3.5 INDOOR AND OUTDOOR AIR QUALITY IN SELECTED RESIDENCES

3.5.1 Measurement Program Design

To learn more about indoor exposures to certain air pollutants, the California Air Resources Board sponsored a separate study coordinated with the epidemiologic investigation of respiratory health in Southern California school children. The "Residential Microenvironmental and Personal Sampling Project for Exposure Classification" (ARB #92-317) was designed to enhance understanding of (1) the concentrations of air contaminants in homes in California, (2) the impact of outdoor air pollution concentrations on indoor air quality, and (3) the influence of certain building characteristics and occupant use patterns on indoor exposures.

Measurements were made, over a 24 hour sampling period, in 125 homes randomly selected from the residences of school children participating in the multi-year health and exposure assessment study. Five of the communities participating in the larger epidemiologic study were selected as the focus for residential sampling. These five communities (San Dimas, Mira Loma, Riverside, Lancaster, and Lake Arrowhead) were selected based on their historical potential for high ambient ozone or particle levels.

The original project goal of 150 study homes was divided approximately equally across communities, with 25 to 30 homes in each of four testing areas, (San Dimas, Mira Loma/Riverside, Lancaster, Lake Arrowhead) with an additional 25 to 30 homes chosen across all five communities for the presence of swamp-type coolers for air conditioning. For the purposes of this study, grouping of the housing stock in Mira Loma and Riverside (two communities with adjacent borders), seemed reasonable. Time limitations, field logistics, and a shortage of equipment allowed for the completion of 125 of the 150-home goal. Homes were studied on two occasions, once during warm summer ambient conditions (denoted as the "hot" season) and once during more moderate spring/fall seasons (denoted as the "cool" season), to address possible variations in housing operation during variable weather (such as the status of windows, open doors, or air conditioning to modify the indoor environment). Homes were recruited on a rolling basis throughout the first half of field operations, based on resident access by telephone or mail, home access for testing, and a field operations directive to sample equally from study communities of interest.

Five different types of measurements (ozone, respirable particulates, formaldehyde, air exchange rates, and airborne acids) were made in and around participating homes. In addition to the sampling measurements, a series of questionnaire surveys designed to gain insight into the operation of the home, a description of house characteristics, and documentation of home operating characteristics during the period of active study sampling was completed by research field staff in all sampling homes studied.

In order to control costs and still provide useful information, a randomized variable sampling scheme was devised for assignment of specific measurements to specific homes (i.e., it was not financially feasible to perform the full complement of sampling in each of the study homes). Twenty-four hour integrated ozone measurements, using the TED sampling approach developed in the epidemiologic study, were made both inside and outside of all ozone-monitored homes (n=121). Inside, sampling was performed in the main activity room (usually the family room or den), while outside measurements were typically made on the back patio or entry area. A subset of homes were sampled both inside and outside for subsequent gravimetric analysis of respirable particles (PM_{10}, for 118 homes and $PM_{2.5}$, for 89 homes). A portion of the homes (inside 98 homes, outside 18 homes) were sampled for 24 hour cumulative levels of formaldehyde. Air exchange rate measurements were made inside 83 homes to learn about entrainment rates of outside air into living spaces. Additionally, a pilot study was performed in and around 12 study homes utilizing a newly developed two-week acid sampler to investigate levels of airborne acidic species around the house.

Field sampling began in the Spring of 1994 and was stopped in late November 1994, when changing regional weather patterns heralded the end of the fall season. A summary of the data set collected during residential sampling is presented in Table 3-20. Discussion of the specific sub-category sampling results is summarized in the appropriate sections below.

3.5.2 Project Objectives

Data from the residential field study were used to meet several identified project objectives. Each of these are discussed, in turn, in the following sections.

3.5.2.1 Assessment and Revisions of the REHEX Model

The REHEX model is a regional exposure model designed to estimate the distribution of exposures to urban air pollutants. In order to estimate individual-level exposures, the model requires new information on the differences between indoor residential air quality and outdoor ambient air pollution concentrations. The residential study was designed to provide information that can be used to modify the REHEX model to estimate the exposures of individual children participating in the Children's Health Study. This procedure will result in the assessment of the applicability and limitations of the REHEX model and modify it, as needed, to address large-scale cross-sectional and prospective epidemiological investigations.

3.5.2.2 Validation of the Revised Exposure Model

After the exposure model is modified, it will be validated using indoor data generated from the residential study. Personal sampling data, when it becomes available

in the future years of the epidemiological project (in Phase III), can also be used to validate the revised model.

3.5.2.3 Comparison of Fixed-Site and Residential Monitoring Data

Each community participating in the epidemiologic study has a community-based air quality monitoring station providing regional air quality data presumed to be representative for the surrounding area. In actual fact, however, relatively little is known about the relationship between air quality measured at these regional monitoring sites and the air quality that exists outside the homes of regional residents. In the course of the data analysis for the residential study, air quality measurements from the station monitors were compared to measurements made inside and outside of the homes participating in the residential monitoring project to evaluate the relevance of regional air quality measurements to residential and personal exposure. Since the measurements were made over complementary time periods (24 hour cumulative for residential sampling, daily or hourly sampling at station sites), the respective data sets can be directly evaluated for comparability.

3.5.2.4 Comparative Exposure Estimates from Interpolation of Regional (Fixed Site) and Residential Monitoring Data

In the same manner as described in the previous section, exposure estimates derived from interpolation of fixed-site monitoring data collected from stations nearest to the homes of participating subjects were compared with exposure estimates derived from microenvironmental and personal sampling measurements gathered in the study.

3.5.2.5 Expansion of Human Exposure Data Base

The data generated in the residential study will greatly enhance the extremely limited information on indoor levels of air contaminants, particularly for the reactive pollutant ozone. This information will be useful in expanding the existing data base on human exposure to include current levels of indoor air contaminants, and to provide a perspective on levels previously hypothesized to produce pulmonary health effects.

3.5.2.6 Indoor/Outdoor Ozone and Air Exchange Rates

Several housing factors and air exchange rate (the number of volumes that are exchanged each hour due to natural or mechanical ventilation) have been hypothesized to influence the ratio of ozone inside and outside of residences. The measurements made at the residences and the information contained in the housing questionnaires, are being used in statistical tests to relate these factors to the ratio of indoor to outdoor ozone. Establishment of the relationships between indoor/outdoor ozone ratios, housing

characteristics, and air exchange rates for a representative sample of study subjects' homes will enable investigators to improve existing models describing human exposure and predicting potential response.

3.5.2.7 A Long-Term Sampler for Fine Particles and Acids

Little is known about the concentration of airborne acids in and around the home. Through support provided from the residential study, a two-week integrated sampler (a modified version of the community TWS sampler) for the measurement of indoor and outdoor acids (both as fine particles and vapors) was developed and deployed. Pilot sampling was conducted at twelve study homes between August and November 1994. Observed nitric acid concentrations ranged from 0.5 to 13 $\mu g/m^3$, with indoor concentrations typically less than half those observed simultaneously outdoors. $PM_{2.5}$ mass data varied from a few $\mu g/m^3$ to over 30 $\mu g/m^3$ indoors, and over a slightly smaller range outdoors. Indoor levels of acetic and formic acids were two to ten times higher than their respective outdoor levels, with appreciable home-to-home variability. The highest observed indoor acetic acid measurement (69.9 $\mu g/m^3$) was collected in a mobile home in the Riverside/Mira Loma area, but values close to this were also observed in more conventional housing in San Dimas and Lancaster. The highest indoor formic acid reading (52.9 $\mu g/m^3$) was recorded in a San Dimas home.

3.5.3 The Residential Study Data Base

The information collected in the course of the residential sampling project will enable investigators to address a wide range of issues important in the understanding of human exposure assessment, as discussed previously. The general measurement approach has been described in Section 3.5.1 above; a more specific methodologic approach is described in the following section, by data measurement type. Measurement types in the study include the determination of ozone, particles, formaldehyde, air exchange rates, acids, and housing survey information.

3.5.3.1 Ozone

In the course of the project, two types of ozone measurements were collected. The participating homes in the study were monitored using the newly developed tool box-sized sampling approach for collection of time-integrated data on area-wide ozone concentrations (the Timed Exposure Diffusive, or TED, sampling approach). In a small number of homes, for quality assurance purposes, monitoring of indoor and outdoor ozone levels was performed using conventional commercially available air monitoring instrumentation (ultra-violet photometers) linked to personal computer data loggers.

3.5.3.1.1 TED Sampling

Ozone was measured inside and outside participating homes for a simultaneous 24-hr period using the Ogawa ozone sampler (developed by Koutrakis and coworkers at the Harvard School of Public Health) housed in a controlled flow/timer sampling box (Timed Exposure Diffusive Sampler, or TED sampler). Evaluation of the TED Sampler approach has been previously reported as a sub-task in the epidemiological study. Study homes were monitored on two occasions, during distinct ozone seasons. One measurement was made during the "summer" season (when warm ambient temperatures and elevated photochemical oxidant conditions were expected, with homes possibly sealed for air conditioning use, or open-windowed if air conditioning was unavailable) and a second measurement was made during the "spring-fall" season (when more moderate temperatures and lower oxidant conditions were anticipated, when homes were more likely to be open-windowed).

Two TED samplers were deployed to each study home for simultaneous sampling inside and outside the residence. At approximately ten percent of the study homes, a co-located TED sampler box was also deployed, either indoors or outdoors, for duplicate QA sampling purposes. Samples were also assigned as field blanks, to provide adequate quality assurance for the collected data.

The TED sampler provides a controlled air velocity sampling regime for the Ogawa passive ozone sampler (described in Section 3.4). The Ogawa sampler contains a nitrite-saturated filter, which is oxidized to nitrate in the presence of ozone. Preparation and analysis of the Ogawa filter sampler was performed in the Los Amigos Research and Education Institute (LAREI) Environmental Health Chemistry Laboratory, under subcontract (this is the same laboratory and personnel providing analytical support for the exposure assessment portion of epidemiologic study). Following exposure in the field and return to the laboratory, samples were analyzed by ion chromatography.

A summary of the ozone data collected in study homes using the TED sampler appears in Table 3-20a. Indoor levels of ozone were, on average, less than 40% of outdoor levels, for the 121 homes sampled (see Table 3-20b). A range of ozone exposures up to levels exceeding the One Hour Standard were observed.

3.5.3.1.2 Ultraviolet Photometry

To verify precision of the TED sampling approach and to provide hourly ozone information in and around residential environments, commercial ultraviolet photometers (Dasibi Corporation Model 1003-AH or equivalent) were used to collect continuous ozone information both inside and outside of ten of the sampling homes participating in the study. The continuous ozone data collection effort was concentrated during the summer sampling season, when peak outdoor ambient levels were expected. The instruments were located indoors for temperature and security reasons, with a Teflon

sampling line placed in the home for indoor sampling and through an opening to the outside for ambient monitoring. Siting of the instruments in the home, and location of the sampling line to the outdoors, were made in conformance with good field operations practices (i.e., using a clean Teflon sampling line, placing inlet away from local sources, locating inlet clear of vegetation canopies, selecting an airy unobstructed sampling domain, and maintaining inlet distance of at least one meter from any wall or solid surface). Instrument readings were monitored by a personal computer, with values recorded to data disk every minute.

3.5.3.2 Particulate Matter

Size-selective particle sampling was performed in participating homes using single-stage impactors developed by Marple (MSP Corporation Model 200 PEM). Two types of sampling heads were used to obtain size information: one sampling head was used to collect particulates smaller than ten microns (PM_{10}) mass median aerodynamic diameter (MMAD) and another was used to collect particles smaller than 2.5 microns MMAD ($PM_{2.5}$). The samplers were virtually identical except for differences in diameters and dimensions of the sampling inlets and color; the $PM_{2.5}$ samplers were magenta in color, while the PM_{10} samplers were gold, to avoid possible confusion. Sampler internal impaction surfaces were oiled with pharmacy-grade mineral oil to minimize particle bounce and reintrainment, as per manufacturer's instructions.

Samples were collected on thirty-seven millimeter filters. Filter samples were analyzed gravimetrically and archived for possible subsequent future analyses. Initial field operations used glass fiber filter media for sample collection, but recurring filter damage to the glass fiber media, caused by directed pressure of the sealing edges of the particulate sampling heads, led to a change in sampling media to Teflon.

Samplers were deployed in the homes by field technicians and used to collect 24-hr samples at a nominal flow rate of 4 liters per minute, utilizing a commercially available personal sampling pump (BIOS AirPro 6000D Personal Air Sampler) operating on house line voltage.

In order to provide comparative information about size-segregated particulate matter in a cost-effective manner, a sampling design involving co-location of PM_{10} and $PM_{2.5}$ samplers in several study homes was developed and followed. Thus, in addition to the separate deployment of $PM_{2.5}$ samplers and PM_{10} samplers in a number of study homes, both samplers were also located side by side in a small number of homes.

As shown in Table 3-20a, $PM_{2.5}$ data showed, on average, a slight excess indoors. This is in conformance with prior expectations, since there are both indoor and outdoor sources for fine particulate mass. Maximum reported outdoor $PM_{2.5}$ levels exceeded 240 $\mu g/m^3$, and were approximately twice as high as maximum indoor $PM_{2.5}$ levels observed.

PM_{10} concentrations also showed, on average, higher levels indoors than outdoors. Numerous indoor PM_{10} sources (such as animal dander, household dust, resuspended materials caused by human, animal, and air movement through the home) are present in most homes and could account for this observation. More strikingly, maximium indoor PM_{10} levels dramatically exceeded the outdoor standard of 50 $\mu g/m^3$ by a considerable margin.

3.5.3.3 Formaldehyde

Formaldehyde (and other carbonyl compounds such as acetaldehyde) in air were collected using cartridges impregnated with purified 2,4-dinitrophenylhydrazine (DNPH) and phosphoric acid, following the method of Fung and coworkers. Samples were collected inside 98 homes to extend existing information about indoor formaldehyde levels. Concurrent with indoor sampling, 18 of the homes monitored also had formaldehyde samples collected outside of the respective residences to provide some information about outdoor levels.

Sampling was accomplished with the use of a flow-controlled sampling pump, fabricated by Fung and coworkers, and operated on house line current for the 24 hour sampling interval. The DNPH sampling cartridges were prepared in Dr. Fung's laboratory and sent to field investigators for home use. Following sample collection in the field, the cartridges were returned to Dr. Fung's laboratory for analysis by high performance liquid chromatography.

As summarized in Table 3-20a, observed formaldehyde levels were generally quite low; no extreme observations were noted. As anticipated, indoor levels were three to four times higher than observed outdoor levels, an indication of the multiple indoor sources outgassing formaldehyde from synthetic furniture, fabrics, and materials.

3.5.3.4 Air Exchange Rates

To better understand the relationship between indoor and outdoor levels of pollutants, air exchange rates were measured in 83 of the study homes. The samples, based on methodology developed by the Brookhaven National Laboratories for use in large-scale field studies (Dietz et al., 1986), were prepared and analyzed by the Harvard School of Public Health.

The sampling method employed a perfluorocarbon tracer (PFT) approach. One or two sources (depending on general house volume and flow) were deployed in the sampling home at least 24 hours in advance of sampling, to permit the PFT level in the home to achieve some equilibrium level. Then, a collection device (capillary adsorption tubes, or CATs) was placed in the main activity room of the home. Collection onto the CAT is accomplished by diffusion of the PFT gas onto the activated charcoal tube, and is primarily a function of house volume (diffusion rates are also sensitive to

temperature, but within the range of home operating conditions in a 24 hour sampling period, this is calculated for 25°C and any correction is considered minor and ignored). Following exposure in the home, analysis of the CATs was performed by gas chromatography (using electron capture detection) in the Harvard laboratory.

Air exchange rate results are summarized in Table 3-20a, and reflect the human tendency to maintain some reasonable control range over home climatic conditions (air exchange rates over the range 0.2 to 1.0, with some extreme cases (exchange rates of 1 to 2).

3.5.3.4.1 House Volume Determinations

To provide the necessary information for determination of housing air exchange rates, housing volume must be documented. In every study home, a floor plan sketch was developed by the field investigation team. The development of a floor plan sketch was aided by the use of electronic distance measuring instruments (EDMI). The EDMI utilize ultrasonic pulses and on-board computer processing to measure linear dimensions at the press of a button.

In each of the study homes measured for air exchange rate, EDMI measurement (or measurement by conventional measuring tape) was performed. In addition, an inventory of home furniture and their approximate volumes was also performed, to correct initial house volume calculations based on an empty box assumption (i.e., that the home volume could be calculated by determining the floor space bounded by exterior walls).

Use of the corrected house volume in the air exchange rate calculations generally provided a consistent adjustment factor of about +0.03 in the hourly air exchange rate value.

3.5.3.5 Acid Species

A newly-designed sampler providing 14-day integrated measurements of acids and fine particles was developed for use in the epidemiologic study and was pilot-tested in the residential project. Four units (two indoor, two outdoor) were delivered to the residential field team for use in measurements in twelve of the participating homes.

During field deployment, participating homes had samplers simultaneously indoors and outside for the two-week sampling period. For the purposes of the pilot measurements, homes were selected on the basis of willingness to participate.

The sampler collects the following pollutant information: gas-phase nitric (HNO_3) and hydrochloric (HCl) acids; fine particle (2.5 micron) mass; fine particle nitrate (NO_3), sulfate (SO_4), and ammonium (NH_4); formic acid (HCOOH) and acetic

acid (CH_3COOH) information. Both denuder and filter pack methodology approaches are used to collect the above information. Sample preparation and analysis of exposed samples were performed in the LAREI chemistry laboratory.

3.5.3.6 Questionnaire Surveys

In addition to sampling in residents' homes, the field operations team collected information regarding housing operation and characteristics by direct observation and interviews with participating residents. To accomplish this in a standardized manner, three types of questionnaires were developed for study use: a baseline residential history describing general home characteristics, an on-site interview/walk-through survey to observe and document home operation and accessories, and a on-site interview/follow-up survey to document actual home operation during the 24 hour sampling period.

3.5.3.6.1 Baseline Residential History Survey

Entry into the epidemiologic study was afforded to all participating school children through a permission form that comprised the first page of a residential/medical history questionnaire. With regard to residential study issues of interest, the survey asked questions about general characteristics of the home (such as numbers of rooms, type of dwelling, presence of air conditioning and type, and kinds of cooking and heating appliances present). These baseline surveys were completed in Spring 1993, and were the basis for subject identification and eligibility selection for residential study participation.

3.5.3.6.2 Technician Walk-Through Survey

During their visits to the study home, field team staff performed on-site interview/walk-through surveys to document housing characteristics in more detail than previously recorded on the baseline questionnaire. Survey information about nearby sources of potential pollution, the type and location of air conditioning and handling equipment, home carpeting, dust control, and the presence of odors were collected by direct observation. In addition, observations from the walk-through survey are being used to confirm information previously reported on the baseline questionnaire.

3.5.3.6.3 Follow-Up Survey

To aid in the interpretation of analytical results of samples collected during the 24 hour sampling period in the study home, field staff also performed a follow-up survey with the resident at the close of sampling activities. The survey documented the actual performance, use, or presence of a range of potential confounding variables such as reintrainment of dust by vacuuming, gardening activities, cooking (frying, grilling, and barbecuing), use of an in-home clothes dryer, operation of the home air handling

system (heat or air conditioning), and the use of fireplaces. In addition to documenting the occurrence of the activity, information was also sought regarding the time period of performance.

3.5.4 Quality Assurance

A substantial quality assurance effort was built into the residential project to provide perspective on the information gathered. Fifteen percent of all samples were assigned to quality assurance/quality control (QA/QC) activities. These were assigned to three areas of concern. Approximately one half of the QA/QC filters (seven to eight percent of the analyzed samples) were assigned as laboratory blanks, to document the overall signal-to-noise ratio in the sampling, handling, and analytical procedures. Approximately one-third of the QA/QC samples (five percent of the analyzed samples) were reanalyzed to quantify laboratory accuracy and precision. The remaining number of QA/QC samples (one-sixth, approximately) were assigned as duplicate and co-located field samples, to establish field site and sampling variability.

3.6 MEASUREMENT OF PERSONAL OZONE EXPOSURE

3.6.1 Measurement Program Design

As indicated in Section 3.1, the objectives of the personal ozone monitoring program were to evaluate personal monitoring devices and collect personal ozone samples and concurrent time-activity diaries for time periods of 7 to 24 hours. The sampler evaluation data were needed to establish the credibility of the devices. The personal ozone data were needed to evaluate and refine the indirect exposure assessment procedure which is embodied in the exposure model.

At the beginning of Phase II, there were no acceptable personal ozone monitoring devices; however, the Harvard group was working on the development of several new personal sampling devices. Since the ARB study did not include personal sampler development work, the schedule for the program was largely determined by Harvard. Fortunately, the Harvard group developed several prototype samplers in time for laboratory testing in Spring 1994 and field testing in California in Summer 1994. The laboratory and field evaluations indicated an active personal ozone sampler was sufficiently accurate and precise to use in the study. Over a period of two days in October 1994, 580 personal ozone samples were collected on 140 sixth grade students in two communities who attended four different schools.

The approach for the methods evaluation involved close coordination with the Harvard group developing personal ozone samplers, interference testing of the Koutrakis badge included in the TED sampler evaluation, separate chamber testing of the passive

badge and an active hollow tube personal sampler, and field testing of both the active and passive badges on 60 children in an "all outdoors" experiment in Riverside. The "all outdoor" experiment (Experiment No. 1) was completed in July 1994.

The intended approach for monitoring of personal ozone levels consisted of three more experiments. In the second experiment, 140 students were monitored on one weekday for personal ozone levels during school (8:00 a.m. to 2:00 p.m.) and after school (2:00 p.m. to 6:00 p.m.). Ozone levels were measured indoors and outdoors at the schools and trained observers recorded their time-activity while at school. Time-activity diaries were given to the children to complete for the afternoon hours. See Section 3.6.53 for more details regarding diaries. Experiment No. 2 provided the opportunity to evaluate the exposure model with almost ideal inputs during the hours the children were in school and the opportunity to test the diary instrument prior to using it on a large group of students. It also provided personal exposure data to assess the relative importance of at-school exposure compared to after-school exposure. Data from this experiment was used to evaluate the adequacy of using I/O ratios and time-activity data to predict personal exposure, which is central to the overall exposure characterization approach.

The research plan called for a third experiment involving collection of personal monitoring data and diary information on children while their homes were being monitored in the residential study. As indicated in Section 3.5, this experiment was not carried out because the personal monitoring device was not available in time for sampling on a sufficient number of students to provide adequate statistical power. The residential program sampled homes from February to November, 1994 and this device was not available for use in the program until September 1994. This important experiment was postponed until Phase III.

A fourth experiment which involved monitoring of 140 students for 10 hours on one weekday and one weekend day was completed. The students completed hourly time-activity diaries on the days when personal ozone sampling was performed. Data from this experiment were used to evaluate exposure model performance on weekdays and on weekend days. The experiment differed from the original Phase II plan in that fewer children were monitored and each child was monitored for 2 days rather than 6 days. This pilot-scale study incorporated the most sampling that could be completed after the device was field tested (August 1994), after access to the schools was established, and before the end of the ozone season (October 1994). The smaller sample size and relatively low ambient ozone levels during the sampling limits the utility of the data for model evaluation and for extrapolation to all participants in the study. Nevertheless, experiments 2 and 4 demonstrated the feasibility of conducting personal ozone sampling with the active personal ozone samplers and provided initial data for testing ozone exposure models.

3.6.2 Background on Personal Ozone Measurement Methods

The Phase II protocol document (Peters et al., 1992a) reviewed the personal ozone measurement methods available in mid-1992 and concluded that none of the available methods could be used to meet study objectives without further development, testing, and refinement. At that time the Koutrakis passive ozone badge appeared to be the most promising method (see discussion in Appendices C and D of Addendum to the Phase II Protocol, Peters et al., 1992b). However, wind-tunnel testing carried out by the Harvard group revealed that the passive sampler's collection efficiency varies significantly with the face-velocity across the sampling surface (Liu et al., 1993). Thus, when deployed as a personal sampler, its collection rate would probably vary as the person moves through the environment. The device could be "starved" in an indoor setting with little or no air movement and could collect unusually high amounts if worn by a person outdoors exercising or in the wind. The needs of the overall study include characterizing the difference in ozone exposure of inactive children who spend most of their time indoors and active children who spend a significant amount of time outdoors. The current passive badge could artificially exaggerate the differences in personal ozone exposure of these two groups of children.

The commercial passive badges (available through Ogawa and Co, USA Inc., Pompano Beach, Florida) contain glass-fiber filters loaded with 100 microliters (µl) of a nitrite-containing solution. In the specific presence of ozone, the nitrite is oxidized to nitrate. Analysis of the collected sample is performed by ion chromatography using readily available chromatographic columns. Several passive sampler improvements and alternate samplers were suggested by the Harvard group in 1994, including

- Use of more uniform preparation techniques for the nitrite-saturated glass-fiber filter used in the passive badge (currently used as the sampling substrate)
- Use of a glass disk sampling substrate instead of glass-fiber (to reduce blank variability and achieve a lower limit of detection)
- Use of as glass-fiber filter coated with less nitrite (to reduce variability and increase detection limits)
- Use of a recently developed active sampler using a hollow tube denuder approach coupled to a mini-sampling pump (to avoid issues of face-velocity bias and to improve minimum detection limits)

Potential interferences, reproducibility, and performance issues of the standard 100-µl filter-based samplers were investigated in 1992 and 1993 (Liu et al., 1993; Liu et al., 1994; Lurmann et al., 1994). The pre-1994 100-µl filter-based samplers had a detection limit of 100 to 200 parts per billion-hours (ppb-hr) ozone, with a sampling media blank variability typically in the 15 to 20 percent range. The glass disk and 50-

μl filter approach were of interest because of predictions that limits of detection might be several times lower for reduced nitrite filters (loaded with 50 μl instead of 100 μl) and perhaps lower still if glass disks were employed as the sampling substrate.

Perhaps the most interesting and promising sampler was the prototype active personal sampler, which used the same chemistry as the passive badge and a denuder as the substrate instead of a filter. The major components of the system consist of a small battery-operated pump and an etched pyrex tube coated with a nitrite-containing solution. Initial tests of the sampling system in the Harvard chamber indicated excellent linear response to ozone from about 0 to 200 ppb in 3- to 4-hr exposures; relatively little effect of humidity over the range 20 to 80 percent; and a detection limit of 7 to 45 ppb-hr, depending on the age of the blanks (Geyh et al., 1994). Harvard performed additional tests to understand the effects of aging on the blanks, and thus on the detection limit. Based on 1993 laboratory tests, the detection limit for the active system (less than about 45 ppb-hr) is significantly lower than the detection limit for the passive badge (between 100 and 200 ppb-hr).

The chemistry of the denuder tube used in the active system is the same as used on the passive badge. Thus the same types of interferences are expected: the filters were not affected by interference from NO_2, nitrous acid, PAN, or SO_2; however, they do respond to nitric acid and hydrogen peroxide, both of which generally have low ambient and indoor concentrations relative to ozone. Another potential interference in Southern California is aerosol nitrate; if deposited onto the denuder surface, nitrate would be measured as ozone. However, as with the denuder in the Two-Week Sampler, a low collection efficiency is expected for nitrate.

3.6.3 Laboratory Evaluation of Personal Ozone Samplers

Multihour chamber experiments were conducted that provided exposures of 25, 75, 150, 300, 600, and 900 ppb-hr ozone for sampler evaluation. The exposure concentrations were selected to provide a range of levels likely to be encountered in ambient sampling, and to provide an opportunity to characterize sampler performance at relatively low levels of exposure. All studies were performed in the LAREI movable exposure facility chamber, and every chamber exposure study was performed twice to provide sampler reproducibility information (to provide data on precision). In the course of each study, triplicate collocated samples were removed at preselected sampling times, as summarized in Table 3-21. All samples were prepared and analyzed in the Harvard laboratory by a member of the Harvard research group (A. Geyh); all chamber experiments were performed at LAREI by a member of the USC research team (E. Avol).

Ozone concentrations in the chamber were generated using in-duct mercury vapor discharge grid lamps whose variable voltage was manually adjusted by the chamber operator. Chamber ozone concentrations were determined by dual ultraviolet photometers (Dasibi Instruments Model 1003) sampling from the chamber through a

glass sampling manifold. Calibration of the instruments was performed using a pen-ray ozone lamp and a transfer standard ultraviolet photometer, calibrated at the SCAQMD reference laboratory.

Passive ozone samplers were placed in TED samplers for sampling in the chamber. The TED samplers were used to avoid potential ambiguities in collection rates due to face-velocity variation during passive sampling and to evaluate ozone sampling approaches during controlled exposures in a manner similar to measurements in classrooms. All TED samplers were manually controlled to tightly define sampling duration and operated on laboratory electrical current during the chamber studies.

Two series of experiments were performed. The scope of these experiments was limited by available physical chamber space and concerns about adequate unobstructed airflow to the sampling units. The first series of experiments involved concurrent sampling by glass disks, 100-µl glass-fiber filters, and denuder tube samplers. The second series of investigations was designed as a comparative evaluation of the 50-µl and 100-µl glass-fiber filter sampling approaches. Identical sampling conditions were attempted for both series, with the same TED sampler, chamber (ozone generation and monitoring system), personnel, and exposure design employed for all experiments.

In the first series of studies, filter and disk samples were both loaded into passive sampler holders and placed in the TED samplers. Flow rates for the TED samplers were checked prior to and following the chamber studies, and all units were found to be in operating compliance. Denuder tubes were used, in conformance with Harvard specifications, with mini-sampling pumps (Spectrex PAS-500 Personal Air Sampler) operating at 65 (± 10 percent) milliliters per minute (ml/min). Flow rates for the personal sampling pumps were measured both before and after each sampling exposure. As necessary, each mini-sampling pump was readjusted prior to each study's use to achieve a nominal flow of 65 ml/min.

In the second series of experiments, passive samplers containing only glass-fiber filter substrates were tested. As in the first series of experiments, all filter-based samplers were placed in the TED samplers for the chamber exposures. No denuder tube measurements were made in this series of experiments. Glass-fiber filters were prepared at Harvard with either 50 µl or 100 µl of nitrite-containing solution. For each experiment, equal numbers of 50-µl and 100-µl samplers were exposed in the LAREI chamber in conformance with the exposure protocol.

All experiments were conducted between late January 1994 and early March 1994 in the LAREI laboratory. Generated chamber ozone concentrations were close to targeted values (see Table 3-22 for a summary of chamber operating conditions, ozone concentrations, and sampler exposure levels; and Table 3-23 for blank value data). The chamber exposure system operated consistently throughout both series of experiments.

Blank value information for the various samplers utilized in the experiment is presented in Table 3-23. The observed LOD for the glass-fiber filters (81 ppb-hr) was approximately half that of the previously observed 200 ppb-hr, and in general conformance with recent batches of filters available from the manufacturer (Anderson, 1994).

Glass disk LODs were quite high (308 ppb-hr) due to large variations in blank levels (39 percent). Denuder blank variability was also large (45 percent), resulting in an LOD of 55 ppb-hr. This LOD was only slightly better than that observed for the 100-µl glass-fiber filters, and considerably higher than the expected value of 7 to 10 ppb-hr, previously observed in the Harvard laboratory. The observed LOD for the denuder tubes was, however, in agreement with that found for a previous batch of tubes sent to USC investigators in November 1993.

In the first series of experiments, filters were compared with disks and denuder tubes. The 100-µl-loaded glass-fiber filters responded in a predictable, monotonically increasing manner. Linearity of response was good, although the slope of the sampler performance line was slightly greater than one. Figure 3-74 summarizes filter performance, showing the line of identity for reference purposes (and the best-fit line intercept, slope, and r value for the filter data collected - each figure presented follows a similar format).

The glass disk samplers responded erratically to increasing levels of ozone (see Figure 3-75). The theoretical ozone sampling rate was between 2 and 3 ml/minute for the glass disk samplers. The apparent sampling rate was much lower and quite variable. The variability in its response to ozone under laboratory conditions was indicative of problems in its performance.

Denuder tube results were more promising than the glass disk sampling approach, but displayed more scatter than the filter data. As Figure 3-76 shows, chamber performance of the denuder tubes was generally good, with a tendency toward slightly increasing scatter at the higher levels of exposure.

A composite performance graph is presented in Figure 3-77, showing the relative performance of each of the three sampling approaches. In this representation, the relatively small variability of the 100-µl filter sampling approach is bounded by that of the denuder tubes. Performance of the glass disk approach is clearly seen as an outlier in comparison to the two alternative techniques.

The second series of chamber experiments assessed the performance of 50-µl filters and 100-µl filters. Observed blank values for the 50-µl filters (59 ppb-hr) were 50 percent lower than those for the 100-µl filters used in this series (118 ppb-hr). Blank variability for the 100-µl filters was higher than that previously found in the filter/disk/tube studies (118 versus 81 ppb-hr), but still approximately half of the

previously observed 200 ppb-hr level. Variability in collocated samples was generally higher in the 50-µl filters. Effective sampling collection rates of both the 50-µl and 100-µl filters were essentially identical, 10.5 cc/min for single-ended filters, which suggested either 50 or 100-µl of solution provides ample collection capacity. Performance of the fiber filters generally followed previous observations, although the 50-µl filter seemed to provide somewhat improved precision over the 100-µl filters.

The chamber experiments demonstrated that the glass disk sampling technique offered no sampling advantages and was determined to be unacceptably noisy in terms of performance scatter. The denuder tube showed promise as a viable sampling approach. Performance was reproducible and predictable, although questions remain regarding blank variability. However, the size and portability of the denuder tube approach make it an attractive candidate for personal exposure sampling.

Efforts to improve the glass-fiber filter approach, by reducing the amount of nitrite-coating solution placed on the filter substrate or coating the filter substrate in a more uniform manner, have met with some success. Blank values on recent batches of prepared filters have supported the contention that a more uniform delivery of solution has reduced sample variability.

Performance testing of the 50-µl versus 100-µl filters demonstrated essentially equivalent responses with lower 50-µl blank value variability. Although the 50-µl filters performed slightly better than the 100-µl samplers (with regard to apparent scatter of repeated sampling at similar concentrations), they did not display dramatic improvements in performance. Conversion to the 50-µl filter sampling approach would require that several potential sampling issues be addressed prior to a decision being reached to change. For example, interference testing for other coexisting pollutants and saturation testing of the reduced amount of nitrite coating solution on the filter would be necessary. Therefore, no modifications to current procedures are recommended at this time.

Although research continues in the Harvard laboratory to improve the performance of the filter-based passive sampler, this series of experiments is convincing in its confirmation of 100-µl filter performance. Additionally, an active sampling approach using a hollow nitrite-coated denuder tube has also demonstrated its potential utility in area or personal exposure sampling. The denuder tube sampling approach offers some advantages for short-term personal sampling. The 100-µl glass-fiber filter passive sampler is clearly the second viable sampling option.

3.6.4 Results of Field Evaluation of Personal Ozone Samplers

The primary objective of the outdoor field experiment was to evaluate the active denuder system under California ambient exposure conditions. A secondary objective was to compare the relative performance of the active system with continuous monitors and passive badges. A single-microenvironment (i.e., ambient) experiment at high ozone concentrations was selected. An additional objective was to demonstrate that the active systems can be worn by children with minimal intrusion (i.e., that they wear them, and not remove them, and that they can continue their normal activities).

The working hypothesis for this experiment was that active denuders compare well with continuous monitors, on average, and that precision for active systems is significantly better than with passive badges. If the hypothesis is true, then active samplers could be used for the remaining personal ozone experiments. The success of the experiment was evaluated against performance criteria similar to those used for the TED/badge sampler: relative precision of about ± 20 percent, relative bias of about ± 10 percent.

The experiment was conducted on July 19 and 21, 1994 at Bobby Bonds Park in Riverside using 6- to 12-year-old children who attended a lunch/recreation program from about 11:30 a.m. until 4:00 p.m. On each day 39 children wore small backpacks for about 2½ hours during normal outdoor activities. The activities included races; playing kickball, soccer, or baseball; reading; doing art projects; going on a nature hike; etc. The children took occasional water and rest breaks, plus a few took bathroom breaks. Adult observers recorded general activities and locations for the children, including when and for how long they might have gone inside or to the bathroom. In general, most of the children spent all of their time outdoors within the area bounded by the continuous monitors and the microenvironmental samplers; this means that the active and passive samples should both agree with the continuous monitoring data, since all were exposed to the same air mass.

Each backpack contained an active sampler with a passive badge attached on the outside. The inlet to the active sampler and the passive sampler were between neck and chest height. In addition, 10 percent of the students carried a collocated active sampler and 10 percent carried a collocated passive badge. One trip blank was collected for every five passive and active samples.

Two continuous ozone monitors were set up about 100 yards apart in the area where the children were going to play, one near the first base line of the baseball field, another near the right field fence. The monitors were calibrated before and after each experiment; the data acquisition system was set up to collect data over 5-min averaging periods.

In addition, four backpacks were designated as microenvironmental samplers. Each contained two active samplers and had two passive badges attached with no rain cap (a cover used by HSPH in later experiments to reduce variations in the face velocity). The microenvironmental samplers were placed under a tree where the children spent some quiet time, under a tent similar to where they took water breaks, and near the two continuous monitors.

The same procedures were used each day, including the following tasks:

- Continuous ozone monitors were set up and calibrated.
- Active sampling pumps were warmed up and their flows calibrated.
- Active and passive samples were prepared.
- Packs were first installed on the children, and then the active samplers and passive badges were placed in or attached to the packs.
- Procedures were followed for recording the start and stop times of the active samplers and the passive badges.
- After sampling, the flow rates of the active sampling pumps were again measured.
- About 10 adult observers watched the children and recorded their activities and general location during the sampling period. A sample of the time-activity log sheet is shown in Figure 3-78.

The laboratory preparations and analyses were performed by Alison Geyh of Harvard. Samples were kept cool at all times, except during sampling, and were shipped to the field and returned to Harvard using an overnight service. Laboratory analyses were performed in four batches, two for each day's experiment. Laboratory results were returned to STI for data processing. Field, laboratory, and data processing procedures are documented in Lurmann et al., 1994.

The results of the field evaluation are summarized below, and presented in Figures 3-79 through 3-81 and Tables 3-24 through 3-28. The blank levels and LOD for the active and passive samplers are shown in Table 3-24. Although there was some variation between analysis batches, the data are consistent: the active sampler's LOD was very low at about 10 ppb-hr; the passive sampler's LOD was higher, about 75 ppb-hr, and similar to the LOD results during the chamber evaluation tests. Individual-batch blank levels were used during data processing.

Ozone concentrations at 5-min averages for the two continuous monitors are shown for the time period of the experiments in Figure 3-79. Note that the personal samplers were operated from 1:24 p.m. to 4:04 p.m. on July 19 and from 1:09 p.m. to 3:49 p.m. on July 21. The two monitors agreed well on both days, implying that the gradient in ozone concentrations in the area was small.

Pairs of microenvironmental samples were placed under a tree, under a tent, and near the two continuous monitors, one near the first base line of the baseball field, another near the right field fence. The results for these samples are presented in Tables 3-25 and 3-26 and illustrated in Figure 3-80. For the active samplers, the pairs agree quite well with each other. The active microenvironmental samples also agreed well with each other; this again implies that the gradient in ozone concentrations in the area was small. The pairs of passive microenvironmental samplers agreed less well within pairs and with passive samplers at other locations. In addition, the active samplers averaged about 6 percent below the continuous monitors, while the passive averaged about 41 percent higher. The higher values for the passive sampler may be due to variations in the sampler collection rate.

Ozone concentrations for the active samplers and passive badges worn by the children, and the continuous monitors are listed in Tables 3-27 and 3-28, and illustrated in Figure 3-81. A total of 78 students wore the samplers, 39 on each day. On July 19, when the continuous monitors averaged 105 ppb, the average for the active samplers was 91 ± 7 ppb. On July 21, when the continuous ozone averaged 141 ppb, the active ozone samplers averaged 136 ± 12 ppb. This is an average negative bias of 8 ± 8 percent, below (better than) the criteria for acceptance of the active sampler as a personal monitoring device. The results for the passive badge are not as good: the passive badges show a positive bias of about 21 ± 19 percent, based on concentration (Table 3-27), or about 18 ± 30 percent, based on ratio to continuous (Table 3-28). In addition, there was at least one outlier well beyond all the rest of the data. Figure 3-81 shows that the distributions of the active samplers and passive badges are significantly different, both in shape and in bias, relative to the continuous monitors.

Conclusions from the field evaluation of the samplers are summarized below:

- The active sampler had a lower (better) LOD than the passive badge: 10 ppb-hr versus 75 pp-hr.

- The ambient ozone concentration, as measured by two continuous monitors, was quite consistent on each day, averaging 105 ppb on July 19 and 141 ppb on July 21.

- The pairs of active microenvironmental samplers agreed quite well with each other and between pairs. The passive microenvironmental sampler results agreed less well.

- The personal ozone concentrations as measured by the active samplers averaged about 8 percent below the continuous monitor (bias), with a precision of about 8 percent. These results demonstrate that the active sampler meets the acceptance criteria set before the experiment.

- The personal ozone concentrations as measured by the passive badges averaged about 21 percent above the continuous monitor (bias), with a precision of about 18 percent. These results do not meet the acceptance criteria set before the experiment. In addition, there were outliers in the data set.

- The personal ozone concentrations as measured by the active samplers had a smaller bias and a lower precision than the concentrations measured by the passive samplers.

- The field evaluation suggests that the active denuder personal sampler can provide sufficiently accurate and precise personal ozone data to use in exposure model evaluation studies. The passive badge does not have sufficient precision or accuracy to meet the needs of this study.

- A small backpack with one or two active samplers inside was worn by students for about 2½ hours without significant problems; this setup was judged to be suitable for additional experiments.

3.6.5 Personal Ozone Sampling Pilot Study

3.6.5.1 Pilot study description

The experiment in Bobby Bonds Park demonstrated that the active ozone sampler performed adequately for a single microenvironment exposure. The next evaluations were done to evaluate the active sampler performance in multiple microenvironments and in situations where the children wearing the monitor were not under constant supervision. Personal sampling in the school and home settings was also needed to generate data on which to test how well a personal ozone exposure model based on time activity diaries and microenvironmental concentrations would predict actual personal exposures. Specifically, the modeling objectives were to:

- Establish indirect exposure model performance with ideal (observed) inputs
- Evaluate the adequacy of model using I/O ratios and self-reporting diary information
- Evaluate the importance of exposure away from school
- Evaluate model performance on multiple weekdays and on weekend days
- Provide a database for model evaluation

A study was designed to measure the personal ozone exposure of elementary school children during and after school hours and on the weekend, thus providing a variance in the level of supervision during sample collection. This design allowed for evaluation of the feasibility of using the active sampler without supervision and assessing the effects of the level of supervision on the quality of the personal measurements.

Sampling started on October 6, 1994 and continued for 4 consecutive weeks, with a week defined as starting Thursday and ending the following Wednesday. One school was visited each week with sampling occurring on Thursday, Saturday, and Tuesday. Four elementary schools that were located in the generally high ozone communities of Upland and Mira Loma were selected for the study. The schools were Pepper Tree and Sky Country Elementary Schools in Upland and Magnolia and Troth Elementary Schools in Mira Loma. Between 27 and 39 children participated each day, generally from two different classrooms. All children were in the sixth grade.

Four different types of personal ozone samples were collected depending on the day of week. On Thursdays, one personal ozone sample was collected extending from the beginning of school to approximately 6:00 p.m. On Saturdays, one sample was collected from approximately 9:00 a.m. to 6:00 p.m. On Tuesdays, one sample was collected from the beginning of school to end of school and a second sample was collected from the end of school to approximately 6:00 p.m. About 10 percent of the children carried a collocated sampler, and trip blanks were collected for about every five samples. For the afternoon Tuesday and all-day Thursday sample, the students were responsible for stopping sample collection in the evening. On Saturday, they were responsible for both starting sample collection in the morning and stopping it in the evening. Students were given watches to help them accomplish this task.

During school hours, a study observer recorded the time activity of the children. For after-school hours, the children were given a small time-activity diary, which they carried with them in their fanny pack. A sample of the diary is provided in Figure 3-82. The children were responsible for recording their sample start and stop times, and an hourly summary of their time activities. To help students accurately fill out their diary, they were given watches set to chime every hour to remind them to write in their diaries. The watches also beeped when it was time for them to stop the sampler. Written instructions were given to the children, which included a phone number where they could reach a member of the study team if they had any questions. In addition to the personal samples, microenvironmental samples using TED samplers were collected in classrooms of participating students and at one central location on the school grounds. Ambient data in the two communities were available from the central community monitoring sites.

Members of the field team were in the school each day of the school week, either to hand out or collect samplers/backpacks, diaries/fanny packs and watches.

When any of the above items were not returned due to absences or because the student forgot, a member of the team retrieved the missing item or ensured that it would be brought to school the next day.

The sampling protocol was as follows:

- Sampling tubes were coated at the Harvard School of Public Health (HSPH) and shipped overnight to the University of Southern California on ice.
- Sampling tubes were shipped with a sheath of protective polyurethane tubing and capped on each end.
- Before being employed in the field each tube was fitted with an inlet, outlet and piece of PVC protective tubing.
- Pumps were turned on 1 to 1½ hours prior to checking the flow rates.
- Sampling tubes were brought to the school cold and allowed to warm during the time that pump flow rates were being calibrated and data log sheets were being prepared.
- On the first day of sampling at a new school, study personnel instructed students in groups of four to five about how to start and stop sampling.
- After the study was completed, the tubes were shipped cold overnight to HSPH.

Additional procedures were followed for each type of sample to ensure consistency among the different communities.

The laboratory preparations and analyses, and initial data processing were performed by Alison Geyh of HSPH. Laboratory analyses were performed in about four batches per school. Laboratory results were returned to STI for data processing and analysis. The time activity diaries were sent to USC, where they were coded into a database. This database was then sent to STI for use in the personal ozone model development.

3.6.5.2 Pilot study results

The results of the pilot personal ozone study are summarized in Tables 3-29 through 3-31, and Figures 3-83 and 3-84. The blank levels and LODs are shown in Table 3-29. There were three to four batches per school, and the blank level used for the personal samples corresponded to the batch that tube was taken from. The average LOD was 8.4 ppb-hr, with a range of 1.7 ppb-hr to 15.2 ppb-hr. The range in blank concentrations was 0.055 μg/ml to 0.569 μg/ml. Thus, there was significant variation

among the different batches. However, given that the sampling times were between 4 and 9 hours, even the batches with the highest blank levels have LODs in the range of 3 ppb for the shortest sampling times. This was sufficient for the purposes of this study. It is worth noting that the passive sampling devices would not have had sufficient detection for this sampling protocol.

Table 3-30 shows the measurement schedule, the number of participants, and the ambient and school microenvironmental concentrations. The ambient concentrations ranged from 33 to 54 ppb. The ambient concentrations were unusually low for these areas and the dynamic range of the concentrations was extremely low for purposes of model testing. The low ambient ozone concentrations during the pilot study severely limited the utility of the data for validation of the personal ozone model. The outdoor school microenvironmental concentrations were similar to the ambient concentrations for Pepper Tree and Troth, while the outdoor school microenvironmental concentrations were lower than the ambient concentrations for Magnolia and Sky Country. The indoor school microenvironmental concentrations were negligible except for Pepper Tree.

Generally, the children were able to follow the instructions for use of the sampler given by study personnel. However, there were several samples which had to be either invalidated or listed as suspect as a result of problems observed by the field and laboratory staff at the time of instrument check-in. These problems included:

- Sampling tubes pulled apart or loose
- Caps on pump removed
- Sampling inlet loose or separated from tube.

Also, during the first week of sampling, some of the tubes were improperly flow tested, which may have resulted in some leaking tubes being used for sampling. As the study progressed, fewer of these problems occurred. Most of the problems were related to the sampler housing. HSPH is presently testing an improved prototype sampler housing that is expected to prevent some of the problems identified in this pilot study. With these improvements, and given the ability of most of the students to use the sampler properly, we expect that the active sampler can be utilized in large field studies without significant problems.

About 10 percent of the children wore collocated monitors to test the precision of the monitor. Most of the microenvironmental samples were also collocated. The average percent difference of the collocations (personal and microenvironmental combined) was 43.1 percent. However, if only samples above 10 ppb were included, the percent difference was 28.4 percent. For only microenvironmental samples above 10 ppb, the percent difference was 40.5 percent, and for only personal samples, the percent difference was 25.0 percent. The fact that the personal samples had better precision was unexpected since there are more potential complications when the sampler is carried by active children than when used as a stationary microenvironmental sampler.

The precision was not nearly as good as obtained in the sampler field evaluation. However, in that study the concentrations being measured were much higher and the children were supervised during the entire sampling period. Also, in the Bobby Bonds Park study, the children were not required to assemble or disassemble the samplers at any time. Thus, the personal sampler can potentially provide reliable data if the children are adequately supervised. The lack of precision in these data significantly limits the usefulness of these data for refinement and evaluation of exposure models.

Figures 3-83 and 3-84 show box and whisker plots of the ranges of personal exposures for each type of sample and each school. These data are also summarized in Table 3-31, which shows the mean, median, and lower and upper quartiles for each day and sample type. For several of the days, the mean exposure was considerably higher than the median exposure. This is due to the inclusion of several outliers, not all shown on the box plots. The difference between the lower and upper quartiles sometimes exceed the average and/or median exposures. This high variability is due in part to the imprecision of the active sampler and in part to differences in the time-activity profiles of the students. The precision of the monitor was not adequately quantified at these low concentrations so we are not able to determine which is most important. However, if a significant amount of the variance is a result of sampler imprecision and if the imprecision also occurs at higher ozone levels, then this original HSPH active sampler is probably not suitable for future studies, (i.e., larger scale summer studies).

On the other hand, the HSPH has re-engineered the packaging of the active sampler (in 1995) to reduce leakage which may improve precision. In addition, the precision data collected at higher concentrations (in the Bobby Bonds Park experiment) were much better than those collected at the low concentrations that occurred in the pilot study. Further testing of the re-packaged active sampler is needed to assess whether it is sufficiently precise to provide data for exposure model development and evaluation.

3.6.5.3 Personal ozone exposure model

Model Description

A personal ozone exposure model was developed based on the microenvironmental approach, which was discussed in detail in the Phase 1 report, (Peters et al., 1992a). Briefly, in the microenvironmental approach, the personal exposure is determined by summing the exposure in each microenvironment that the subject spends time during the exposure period. Our personal exposure model breaks the sampling period of the subject into 20-minute increments, and assigns a microenvironment (including whether the subject was indoors or outdoors) for each time increment, and then uses this information to assign an exposure to that increment as will be described below. The total exposure for that individual is determined by summing the exposures in each time increment.

The time-activity diary given to the children was divided into 1-hr blocks. For each hour, the child was asked, "Where were you during this time?", and "What amount of time was spent outdoors?" For the first question, the possible answers were: (1) home, (2) near home, (3) school, and (4) other. We only have indoor and outdoor data for the school microenvironment. For the three other microenvironments, we used the hourly ambient monitoring station data in that community, and for indoor exposures in these microenvironments, we used an indoor/outdoor ratio of 0.2, which was the preliminary estimated average indoor/outdoor ratio for ozone from the residential study. The indoor/outdoor ratio determined from the final residential study data was somewhat higher (0.3). Given the amount of time the children spent in their residences, this difference in I/O ratio will only have a minor effect on the exposure estimates. The children had the option of choosing more than one answer to this question if they were in more than one microenvironment during this period. If the children checked two microenvironments and circled one of them to indicate that they were in that one the most, then 40 minutes were assigned to the microenvironment circled as being in the most and 20 minutes to the other. If they checked two microenvironments and did not circle where they were most, one microenvironment was randomly assigned 40 minutes and the other 20 minutes. If the children checked three microenvironments, regardless of whether they circled one as being in the most, 20 minutes were assigned to each microenvironment.

The choices for the amount of time outdoors question were: (1) none, (2) some, (3) most, and (4) all. The amount of time outdoors was assigned as follows:

(1) None - 0 minutes
(2) Some - 20 minutes
(3) Most - 40 minutes
(4) All - 60 minutes

There was also a question for the amount of time in travel, but because we do not have extensive information on transportation exposure, we did not use this data. The travel time was typically only a small portion of the total exposure time, so it should not significantly decrease the predictive ability of the model.

The children did not always fully complete the diary. If a child did not complete more than 3 hours during the sampling period, then this measurement was not used in the subsequent analysis. If data were missing for 3 hours or less, then the missing hours were assigned microenvironments (including whether they were indoors or outdoors) based on the distribution of responses of the other children during the particular hour and sample type. For children where this was necessary, a flag was added to denote that part of the diary was completed by using average values. In addition, as discussed above, a "QA/QC" flag was included that denoted which active sampler results were considered suspect by the field or laboratory technicians.

Model Results

The personal ozone model, based on I/O ratio and time-activity diary data, was developed to evaluate how well this type of information can be used to predict personal exposures as a surrogate for actual personal measurements. We also investigated how well ambient data predicted personal exposures. Regression results for these models are shown in Table 3-32. Three levels of data were used: (1) all data, (2) only non-suspect data, and (3) only non-suspect data with complete time-activity diaries. For the regression of the personal exposure versus the model predicted exposure, the correlation was poor when all the data were included, and improved for the next two levels. For the complete and non-suspect data, the model predicted 21 percent of the variation in the data, and the ratio of the personal exposure mean to the model predicted mean was 0.73. This indicates that the model over-predicted the personal exposure. A plot of the personal exposure versus the model prediction is shown in Figure 3-85. While the correlation was low, it was significantly better than the prediction based on ambient concentration alone, which only predicted 6 percent of the variation in the personal exposures. The ratio of means between the personal exposure and ambient concentrations was 0.28, indicating that the personal exposure is about a quarter of the ambient concentration. Another model, which estimated personal exposure only from the time spent outdoors and the outdoor community monitor ozone data, predicted 13 percent of the variation in the personal ozone data.

The data were further divided by sampling type, and the results are shown in Table 3-33. The Tuesday morning sample had the highest correlation, predicting 44 percent of the variation. The ratio of means was also very close to one. This was not unexpected because the children were at school and supervised for this entire sampling period, thus their location and the ambient concentration to which they were exposed were known. However, even though the ratio of means is near one, the slope of the model is less than one (0.56), and the intercept is greater than zero (3.28). This indicates that the model underpredicted low exposures and overpredicted the high exposures. The other three sampling types had significantly lower correlations.

The data were also divided by school, and these results are shown in Table 3-34. The highest correlation was for Magnolia. However, the slope for Magnolia was close to zero and statistically non-significant. The slopes for Sky Country and Troth were closer to unity, but the correlations were lower. The better slopes at Sky Country and Troth may reflect the lower frequency of sampler problems in the last two weeks of the study.

Finally, the data were grouped by sampling type and school. Within each of these groups (16 = 4 sampling type x 4 schools), the personal exposure and the ambient concentration were averaged. This technique allows for the averaging of some of the sampler imprecision. Figure 3-86 displays the average personal exposure and average ambient exposure. A regression on the data yielded a correlation coefficient of 0.46,

which is significantly better than the correlation (0.06) using individual personal samples. Because the estimates of personal exposure for children were not evenly distributed, the median personal exposure data were also compared to ambient data (see Figure 3-87). A regression on the median exposure data yielded a correlation coefficient of 0.42, which is also considerably better than with the individual personal samples. These group data provide stronger evidence that personal exposures are linked to ambient ozone concentrations.

The following conclusions can be drawn from the results of the pilot personal ozone study and corresponding personal ozone model validation:

- The active sampler had a sufficiently low LOD for short-term personal sampling, (LOD averaged 8.4 ppb-hr in 15 batches; the LOD ranged from 1.7 to 15.2 ppb-hr).

- Children were generally able to follow the instructions for using the sampler, but there were some problems with parts of the sampler being separated while sampling.

- Precision of the active sampler was ±43.1 percent for all samples, and ±28.4 percent for samples above 10 ppb. The precision in the pilot study was not nearly as good as in the Riverside field evaluation of the sampler where the precision was ±8 percent.

- There was high variability among the measured personal exposure concentrations. However, on average, the personal ozone exposures were only 28 percent of the ambient ozone levels.

- For all non-suspect samples with complete corresponding diaries, the personal ozone exposure model predicts 21 percent of the variability in the personal measurements.

- Ambient ozone concentrations were only able to explain 6 percent of the variability in the personal measurements.

- The personal ozone exposure model performed best (i.e., highest r^2) on samples where the children were supervised for the entire sampling period and where the children were at school, rather than at home or elsewhere.

The low precision of the samplers used in this study significantly limit the development of an adequate model. However, given the imprecision of the monitor, it is significant that the personal exposure model provided considerably better predictive power than the model using only the ambient concentration data alone.

3.7 MODELING INDIVIDUAL AIR POLLUTION EXPOSURE

3.7.1 The Model

As noted above, one of the objectives of the exposure assessment program is to develop individual exposure estimates for the study participants for each year of the study. Because it is not possible to directly measure the personal exposure to the pollutants of interest on every participant for every hour of every year (or anything close to this), the individual estimates must be derived from personal exposure models. Although most of the exposure assessment resources in Phase II were devoted to collecting the data needed as inputs to the exposure model, a small effort was made to develop prototype exposure models for ozone and NO_2. No attempt was made to model personal PM exposure in Phase II because PM has not yet been measured in the schools and PM data from the residential program were not available during Phase II.

All modern exposure models use the microenvironmental approach where the integrated exposure is estimated as the sum of the exposures in each microenvironment occupied by the individual for the time period of interest (Sexton and Ryan, 1988), as shown below.

$$E_{ij} = \sum_{m=1}^{M} C_{ijm} \, \Delta t_{ijm} \qquad (1)$$

where

E_{ij} = integrated exposure of the ith individual in the jth community
C_{ijm} = concentration in the mth microenvironment when it is occupied by the ith individual in the jth community
Δt_{ijm} = amount of time the ith individual in the jth community spent in the mth microenvironment

In order to express exposure in the familiar units of concentration, rather than concentration-time, the time-weighted-exposure (*TWE*) is commonly used. It is calculated from

$$TWE_{ij} = \frac{1}{\sum_{m=1}^{M} \Delta t_{ijm}} \sum_{m=1}^{M} C_{ijm} \, \Delta t_{ijm} \qquad (2)$$

This approach is used in the Regional Human Exposure (REHEX) model (Lurmann et al., 1989; Lurmann, 1993) and the NAAQS Exposure Model (McCurdy and Johnson, 1989), which are designed to estimate the distribution of exposures to urban air pollutants for the general population. Substantial modifications were made to the

REHEX model in this study to allow it to estimate personal exposures for epidemiologic purposes. The microenvironmental approach requires assignment of a microenvironment for each person during each part of the day and estimation of the concentration in that microenvironment. The microenvironment assignment procedures and microenvironmental concentration estimation procedures used in the prototype model are described below.

The assignment of microenvironments was principally based on the annual time-activity questionnaire data collected in 1993. The questionnaire asked the students to estimate the amount of time they spent outdoors for various periods during the day for non-summer weekdays (i.e., school days), non-summer weekends, and summer days. This division of types of days was used for the modeling database. Our knowledge of the school schedules and information in the diaries allowed us to consider three microenvironments: (1) indoors at home, (2) indoors at school, and (3) outside. The questionnaire asked the students to base their estimates for these particular types of days on the last 2 weeks for the non-summer period and a typical 2-week period for the summer. The students' responses were expressed as the number of days (e.g., 0 to 10 weekdays in the 2-week period) that they were outdoors for a particular time period. In the modeling database, the assignments for each day of the year were made probabilistically based on the data. The questionnaire data only covered selected hours of the day; assumptions were necessary to assign microenvironments for the non-surveyed hours of the day. The procedures and assumptions for the microenvironmental assignments are listed below.

Non-Summer Weekday

- Midnight to 8:00 a.m. and 6:00 p.m. to midnight were assigned indoors at home.
- 8:00 a.m. to 2:00 p.m. were assigned indoors at school.
- Two hours, randomly chosen, between 6:00 a.m. and 2:00 p.m. were assigned as outdoors.
- 2:00 p.m. to 6:00 p.m. were assigned probabilistically, based on the survey data.

Non-Summer Weekend

- Midnight to 9:00 a.m. and 9:00 p.m. to midnight were assigned indoors at home.
- 9:00 a.m. to 6:00 p.m. were assigned probabilistically, based on the survey data.
- 6:00 p.m. to 9:00 p.m. were assigned 40 minutes outdoors for the 3-hr period, randomly selected. This was considered a reasonable estimate for 9 to 18 year-old children.

Summer

- Midnight to 9:00 a.m. and 9:00 p.m. to midnight were assigned indoors at home.
- 9:00 a.m. to 9:00 p.m. were assigned probabilistically, based on the survey data.

The microenvironmental assignments were made in 20-minute increments for each day of the year. The survey typically asked if the student spent at least half of the time outdoors for each time period (e.g., 2 hours out of a 3-hr period, or 30 minutes out of an hour). Thus, for each hour in the survey reported as principally outdoors, 40 minutes were assigned to outdoors activities. The other 20 minutes were assigned as indoors at home or indoors at school, as appropriate.

The basis for the concentration estimates for each microenvironment was the hourly ambient ozone and NO_2 data collected in each community. For the outdoor microenvironment, the exposure was simply assigned the ambient concentration for that hour. During the school monitoring program, the indoor and outdoor ozone concentrations were measured at 48 of the 50 schools in 1993. The average ozone indoor to outdoor ratio over the 1993 and 1994 sampling periods for each school was calculated and used to determine the school microenvironment. For schools where no measurements were made, the preliminary average (0.19) from all of the schools was used. For nitrogen dioxide, there were no school measurements, so a nominal indoor/outdoor ratio of 0.5 was chosen from the literature (Spengler et al., 1994). The exposure estimation was then made by multiplying the community monitoring site concentration by the indoor/outdoor ratio.

Data were not available for indoor concentrations or for the indoor/outdoor ratios at individual student's residences. The preliminary data from the companion residential study indicated that the typical indoor/outdoor ratio for ozone in Southern California residences was about 0.2. The final data from the companion residential study indicates that the mean indoor/outdoor ratio for ozone is somewhat higher (0.3). Nevertheless, the value of 0.2 was used for all of the students' residences. For nitrogen dioxide, there was also no student-specific information on the indoor/outdoor ratio. However, the housing questionnaire did ask the students if their homes had gas stoves and/or gas pilot lights, which are known to increase indoor nitrogen dioxide concentrations. Spengler et al., (1994) has found in the Los Angeles Basin that the typical indoor/outdoor ratio for nitrogen dioxide is about 0.4 when there is no gas stove or pilot light. When there is a gas stove, the indoor concentration is typically 12 ppb higher, and when there is also a pilot light the indoor concentration is about 15 ppb higher. Thus, for nitrogen dioxide there are two additional microenvironments: (1) indoors at home with gas stove without a pilot light and (2) indoors at home with gas stove with pilot light.

3.7.2 Results for Ozone

Individual estimated ozone exposures were generated for all of the students evaluated during the 1993-94 school year for the May to September period (the summer ozone season in Southern California). Box-whisker plots of the average 10:00 a.m. to 6:00 p.m. ozone exposures for students in each community are shown in Figure 3-88. The average estimated exposure and ambient concentrations during this period are compared in the lower portion of the figure. All of the individual ozone exposure

estimates were below the ambient concentrations for their community. The within-community variance in estimated exposure is significant, which should ultimately enhance the statistical power of the study to detect effects. The within-community variance is underestimated in these calculations because none of the variations in indoor/outdoor ratios for individual residences are included.

The model estimates also suggest that between-community variance is significant and important. For example, Figure 3-88 shows that the interquartile ranges for the low ozone communities of Lompoc, Long Beach, Atascadero, and Santa Maria do not overlap with the interquartile ranges of most of the other communities. There is significant overlap of the interquartile ranges between the moderate and high ozone communities; however, the upper-quartiles of the high ozone communities are significantly higher than those for the moderate ozone communities.

The results from the ozone exposure model are interesting and plausible, however, they have not been verified. Additional personal ozone exposure data, in conjunction with residential measurements and time-activity diaries, are needed to provide a database for model evaluation and model refinement.

3.7.3 Results for Nitrogen Dioxide

Individual estimated nitrogen dioxide exposures were generated for the 1993-94 school year students for January to December, 1994. Box and whisker plots of the distributions of annual estimated personal NO_2 exposures in each community are shown in Figure 3-89. A comparison of the mean estimated exposure and the 1994 ambient NO_2 concentrations is presented in the lower portion of the figure. The ambient concentration and mean exposure for NO_2 are correlated, but not as strongly as those for ozone. The model estimates large ranges of individual NO_2 exposure within each community (note the extended lower tails of exposure distributions in several communities). The large range is due to the bimodal distribution of indoor NO_2 concentrations resulting from homes with and without significant indoor sources of NO_2. The results suggest that if the presence of gas stoves and pilot lights were not accounted for, the individual NO_2 exposures would be significantly misclassified. Also, for communities with low ambient concentrations, the indoor source contributions were dominant and the estimated personal exposures exceeded the ambient concentrations. For the communities with higher ambient NO_2 concentrations, the ambient concentrations dominate personal exposure. The NO_2 results also suggest that if efforts are not made to classify on the basis of personal exposures, there will be a loss of statistical power as a result of the large variations of personal exposure within communities. At the very least, adjustments need to be made to account for the large effects of gas stoves and pilot lights. Variation in personal exposure, if accounted for, increases power while unaccounted for variation decreases power.

3.8 SUMMARY AND CONCLUSIONS

3.8.1 Exposure Assessment

3.8.1.1 Two-week aerosol/acid sampler development

An extensive effort involving laboratory component testing, field component testing, and complete system field testing was undertaken to develop a Two-Week Sampler (TWS). The performance of the new sampler exceeded the accuracy requirements for measurements of $PM_{2.5}$ mass, $PM_{2.5}$ sulfate, $PM_{2.5}$ nitrate, and $PM_{2.5}$ ammonium aerosol. For nitric acid, the sampler has a 15- to 30-percent positive bias. The accuracy of the sampler for hydrochloric acid, formic acid, and acetic acid was not assessed. Seventeen samplers were built for the project. During the first year of sampling, the samplers had adequate precision (±15 percent) for differentiating the concentrations between the 12 communities.

3.8.1.2 Time Exposure Diffusion ozone sampler development

A Timed Exposure Diffusion (TED) ozone sampler that uses the Koutrakis ozone measurement method was developed to facilitate economical and concurrent sampling in a large number of schools. Laboratory evaluation of the sampler showed that it was not affected by interference from NO_2, nitrous acid, PAN, or SO_2. However, it does respond to nitric acid and hydrogen peroxide, which both generally have low ambient and indoor concentrations relative to ozone. Field evaluations showed the device was able to measure ozone with a +6 percent bias and ±12 percent precision on average, which meet the study's requirements. Fifty TED samplers were built for the program.

3.8.1.3 Personal ozone sampler evaluation

The Koutrakis active hollow tube denuder, which uses a sodium nitrite-coated denuder together with a small pump, was tested over a broad range of concentrations in the laboratory chamber. The results showed that it had a lower limit of detection than the passive Koutrakis badge and that it measured ozone with little bias and good precision.

An "all outdoor" experiment was conducted where personal ozone was sampled for 2½ hours on 78 children on two summer afternoons in Riverside. Ambient ozone concentrations were 100 to 140 ppb on these afternoons. Each child had both the Koutrakis passive ozone monitor and the Koutrakis active hollow tube denuder. Wearing an active denuder in the backpacks did not interfere with the children's activities. The data show the personal ozone levels measured by the active monitoring device were 8 ± 8 percent lower than the stationary continuous monitoring data on average. The passive device ozone data were 18 ±19 percent higher than the stationary continuous monitoring data on average and had outliers. The field evaluation suggested

the active hollow tube denuder can provide sufficiently accurate and precise personal ozone data to use in exposure model evaluation studies when the children are adequately supervised and when ambient ozone concentrations are 100 ppb or higher. If the children are not supervised, precision of the data may be compromised prohibiting their use in the refinement of evaluation of exposure models. The passive sampling device does not have sufficient precision to meet the needs of the study, although it may be useful for categorizing a subject's ozone exposure as high, medium or low.

3.8.1.4 Current ambient air quality in the 12 communities

The first full year (December 1993 to December 1994) of measured ambient air quality data in the 12 communities indicates the concentrations of ozone, NO_2, and PM_{10} are generally in agreement with the expected pollutant profiles. The measured concentrations of gaseous inorganic acids (HNO_3 and HCl) do not agree as well with the study design profiles as those for ozone, NO_2, and PM_{10}. Atascadero, Santa Maria, and Lompoc have low concentrations of all pollutants relative to the other communities, and San Dimas, Upland, Mira Loma, and Riverside have moderate or high concentrations for all pollutants. These are good choices for unpolluted and polluted communities.

For ozone, 10 of the 12 communities have the expected profiles based on the annual average daily 1-hr maximum values and all of the communities have the expected profiles based on the May to September "high ozone season" data. The annual average ozone at Upland and Mira Loma was lower than expected, but both communities rank as high for ozone based on the "high ozone season" data. Lake Arrowhead stands out as the highest ozone community.

For NO_2, 10 of the 12 communities have the expected relative concentration rankings. The exceptions are Lancaster, which has moderate NO_2 levels rather than low levels, and Lake Arrowhead, which has low levels rather than moderate levels. These differences are minor and will not affect the ability of the study to detect effects of NO_2. Upland is the highest NO_2 community in the study.

For PM, 10 of the 12 communities have the expected relative concentrations based on PM_{10} and 11 of the 12 communities have the expected relative concentrations based on $PM_{2.5}$. San Dimas and Riverside have moderate PM_{10} levels rather than high PM_{10} levels; however, both have high $PM_{2.5}$ levels. Lancaster has low $PM_{2.5}$ levels rather than the moderate levels expected; however, it has moderate PM_{10} levels. Mira Loma stands out as the highest PM community. The PM_{10} levels at Riverside were surprisingly low compared to those at Mira Loma and the historical PM_{10} levels at Rubidoux; both of these sites are within 15 km of the Riverside monitoring station. Efforts are underway (in Phase III) to investigate the cause of the unexpectedly low PM_{10} concentrations at Riverside.

For inorganic acids, seven of the 12 communities have concentrations that match the expected profiles (two high-acid, two moderate-acid, and three low-acid communities match). However, Lancaster and Long Beach had low and moderate levels, instead of high levels, and Alpine and Mira Loma had moderate instead of low levels. The largest deviation from the design profile was at Riverside which had high levels instead of expected low levels. The organic acid levels exceeded the inorganic acid levels at all sites; the relative ranking of communities for organic acids was mostly similar to that for inorganic acids. The absence of low inorganic acid concentrations at Riverside and Mira Loma, where other pollutants are high, may compromise the ability of the study to separately detect the effects of acidic species from ozone, NO_2, and PM. This issue will be evaluated in more detail in Phase III (see section 4.8).

Overall, the observed ranges of long-term average concentrations between the unpolluted communities and the most polluted communities are in agreement with the design expectations (i.e., factors of three to five differences in annual average concentrations).

3.8.1.5 Ozone at schools

The TED sampler 8:00 a.m. to 3:00 p.m. integrated ozone data indicate indoor ozone levels were low relative to outdoor levels in almost all schools. The indoor concentrations ranged from below the detection limit (8 to 10 ppb) to 40 ppb, while the outdoor concentrations ranged from 10 to 120 ppb. Almost half of the indoor ozone concentrations were below the detection limit of 8 to 10 ppb, which was a somewhat surprising result. The mean indoor/outdoor ratio was 0.32 for samples with concentrations above the LOD. The highest ozone concentration measured indoors was 40 ppb, which is comparable to the tropospheric background concentration at this latitude. The low indoor ozone levels and low indoor/outdoor ratios are believed to be due to the prevalence of air conditioning in the schools, which usually results in low ventilation rates because the windows are closed when the air conditioning is used.

3.8.1.6 Within-community variance in ozone

The school outdoor ozone data indicate there was modest within-community variance in ambient ozone concentrations. In most cases, the 8:00 a.m. to 3:00 p.m. integrated ozone concentrations outdoors collected at different schools were within ±20 ppb of the levels recorded at the community monitoring station. In other cases, differences as large as 40 ppb (80 versus 120 ppb) were observed.

3.8.1.7 Pilot study of children's ozone exposures

A pilot personal ozone monitoring study was conducted on 140 sixth grade students in San Dimas and Mira Loma in October. The ambient ozone concentrations during the study were unusually low and had a small dynamic range (daytime

concentrations of 33 to 54 ppb). The pilot study demonstrated the feasibility of using the newly developed active personal ozone sampler on children for short-term (4 to 9 hours) sampling along with hourly time-activity diaries. For part of the sampling, the children were unsupervised and were required to assemble and disassemble the sampler. The active samplers had adequately low limits of detection for the experiment, but its precision was substantially poorer than in the summer field evaluation in Riverside. Subsequent to the pilot study, the HSPH researchers re-engineered the active sampler to address the leakage and assembly/disassembly problems discovered in this pilot study.

The personal ozone data showed there was high variability among the students' exposures and the average personal ozone levels were only 28 percent of the ambient. Analysis of the individual data indicated that the ambient ozone concentrations explained only 6 percent of the variance in personal exposure. However, when the personal ozone data was grouped by sample type and school, the ambient ozone explained 46 percent of the variance in average personal ozone. This result clearly establishes the linkage between personal and ambient ozone.

An exposure model that used the ambient concentrations in conjunction with the students' time-activity diaries explained 21 percent of the variance in personal ozone exposure. The low levels and lack of dynamic range in the ambient ozone concentrations along with the poorer precision of the data limited the utility of the data for model evaluation. Future personal ozone experiments should be conducted in summer, rather than October in order to capture a broader range of concentrations, and with re-engineered personal samplers to improve precision.

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Table 3-1. The initial dates of the air monitoring for Phase II.

Monitoring Site	Initial Date of Pollutant Monitoring				
	Ozone	NO_2	PM_{10} TEOM	Acids and $PM_{2.5}$ Aerosol	Temp and Humidity
Atascadero	E[a]	E	12/01/93	12/16/93	N[b]
Santa Maria[c]	E	12/14/93	12/04/93	12/16/93	E
Lompoc	10/30/93	10/30/93	10/30/93	12/16/93	N
Lancaster	E	E	11/14/93	12/15/93	E
San Dimas	10/16/93	10/16/93	10/16/93	12/16/93	N
Upland	E	E	11/05/93	12/16/93	E
Long Beach	E	E	E	12/15/93	E
Mira Loma	10/15/93	10/15/93	10/15/93	12/16/93	N
Riverside	09/25/93	09/25/93	09/25/93	12/16/93	N
Lake Elsinore	E	11/03/93	11/03/93	12/16/93	N
Lake Arrowhead[d]	03/15/94	03/15/94	03/11/94	03/14/94	03/10/94
Alpine[e]	E	E	02/25/94	02/25/94	02/25/94

[a] E = Existing monitoring equipment operated by ARB or a local district.

[b] N = Nearby monitoring equipment by NWS or local district.

[c] ARB approval was not obtained until December 1993.

[d] Site approval by the school district was not received until February 1994.

[e] The San Diego APCD did not approve installation of additional equipment until late January 1994.

Table 3-2. Summary of the 1994 annual average ozone levels in the 12 communities.

Community	24-hr Average O_3 (ppb)	10am-6pm Average O_3 (ppb)	2pm-6pm Average O_3 (ppb)	Average Daily 1-hr Maximum O_3 (ppb)
Atascadero	24.8	41.5	40.3	50.2
Santa Maria	21.7	30.0	29.1	37.1
Lompoc	28.4	37.6	37.9	42.7
Lancaster	33.2	46.3	50.4	59.4
San Dimas	26.9	61.0	61.1	83.1
Upland	25.2	52.7	57.4	73.1
Long Beach	18.8	28.7	28.7	41.2
Mira Loma	27.1	58.5	57.6	75.0
Riverside	30.6	63.6	64.3	80.2
Lake Elsinore	35.7	60.6	62.1	75.0
Lake Arrowhead	70.8	84.2	93.0	106.3
Alpine	44.0	62.4	59.2	76.7
Average	32.3	52.3	53.4	66.7

Table 3-3. Summary of additional 1994 annual average ozone exposure metrics.

Community	Hours Per Month with $[O_3]$ > 60 ppb	Hours Per Month with $[O_3]$ > 90 ppb	Hours Per Month with $[O_3]$ > 120 ppb	Hours Per Month with $[O_3]$ > 150 ppb	ppb-Hours Per Month with $[O_3]$ > 60 ppb[a]	ppb-Hours Per Month with $[O_3]$ > 90 ppb[a]	ppb-Hours Per Month with $[O_3]$ > 120 ppb[a]	ppb-Hours Per Month with $[O_3]$ > 150 ppb[a]
Atascadero	27.4	0.8	0	0	1907	78	0	0
Santa Maria	2.2	0.4	0.2	0.1	182	54	35	21
Lompoc	6.5	0.2	0	0	435	16	0	0
Lancaster	73.4	11.7	1.0	0	5948	1272	133	0
San Dimas	94.9	51.8	25.9	10.2	9770	6597	3881	1768
Upland	77.1	43.9	21.6	6.9	8312	5711	3273	1243
Long Beach	9.5	1.0	0.2	0.1	760	115	24	13
Mira Loma	95.7	47.0	13.2	2.4	8991	5396	1863	425
Riverside	117.5	64.7	26.5	5.4	11642	7718	3721	929
Lake Elsinore	106.2	30.8	8.1	1.8	9452	3600	1159	311
Lake Arrowhead	361.6	146.1	62.3	21.0	33583	17776	9069	3564
Alpine	137.0	31.9	2.4	0	10938	3302	318	0
Average	92.4	35.9	13.5	4.0	8493	4302	1956	689

[a] Weighted sum of the hours above the threshold concentration multiplied by the concentration.

Table 3-4. Summary of May to September 1994 average ozone levels in the 12 communities.

Community	24-hr Average O_3 (ppb)	10am-6pm Average O_3 (ppb)	2pm-6pm Average O_3 (ppb)	Average Daily 1-hr Maximum O_3 (ppb)
Atascadero	30.0	48.7	45.9	58.2
Santa Maria	22.5	29.5	28.6	37.0
Lompoc	23.3	30.8	30.7	34.9
Lancaster	48.4	64.3	72.9	84.3
San Dimas	37.9	92.2	92.1	125.7
Upland	40.5	88.4	97.0	119.2
Long Beach	27.5	40.0	40.5	55.5
Mira Loma	37.8	86.1	84.1	107.9
Riverside	45.5	97.1	97.9	121.1
Lake Elsinore	47.4	79.4	81.6	100.6
Lake Arrowhead	81.9	103.6	118.8	136.7
Alpine	47.2	72.4	66.8	90.0
Average	40.8	69.4	71.4	89.3

Table 3-5. Summary of additional May to September 1994 ozone exposure metrics.

Community	Hours Per Month with $[O_3]$ > 60 ppb	Hours Per Month with $[O_3]$ > 90 ppb	Hours Per Month with $[O_3]$ > 120 ppb	Hours Per Month with $[O_3]$ > 150 ppb	ppb-hours Per Month with $[O_3]$ > 60 ppb[a]	ppb-hours Per Month with $[O_3]$ > 90 ppb[a]	ppb-hours Per Month with $[O_3]$ > 120 ppb[a]	ppb-hours Per Month with $[O_3]$ > 150 ppb[a]
Atascadero	50.4	2.0	0	0	3541	188	0	0
Santa Maria	3.8	0.8	0.4	0.2	319	108	69	41
Lompoc	4.0	0.4	0	0	288	37	0	0
Lancaster	159.8	27.4	2.4	0	13062	2992	318	0
San Dimas	180.8	112.0	59.8	23.6	19547	14434	8970	4085
Upland	168.2	101.6	51.2	16.6	18514	13274	7774	2982
Long Beach	20.0	2.4	0.4	0.2	1608	278	58	32
Mira Loma	184.2	103.0	29.4	5.8	17953	11878	4161	1021
Riverside	231.8	142.0	60.2	12.8	23822	17068	8483	2198
Lake Elsinore	196.8	66.0	18.4	4.4	18008	7776	2652	746
Lake Arrowhead	475.4	233.6	108.8	40.2	46789	29042	15998	6832
Alpine	197.6	54.0	4.0	0	16119	5595	520	0
Average	156.1	70.4	27.9	8.6	14964	8555	4083	1495

[a] Weighted sum of the hours above the threshold concentration multiplied by the concentration.

Table 3-6. Summary of 1994 annual average and May to September ambient nitrogen dioxide levels in the 12 communities.

Community	May to September 24-hr Average (ppb)	Annual 24-hr Average (ppb)
Atascadero	11.8	14.0
Santa Maria	4.8	5.0
Lompoc	2.9	4.2
Lancaster	18.2	18.9
San Dimas	39.2	35.8
Upland	44.0	40.9
Long Beach	28.6	34.8
Mira Loma	28.3	29.8
Riverside	27.6	32.6
Lake Elsinore	17.9	20.4
Lake Arrowhead	6.8	8.2
Alpine	14.0	12.9
Average	20.3	21.5

Table 3-7. Summary of 1994 annual average ambient PM_{10} levels in the 12 communities.

Community	24-hr Average PM_{10} ($\mu g/m^3$)	10am-6pm Average PM_{10} ($\mu g/m^3$)	2pm-6pm Average PM_{10} ($\mu g/m^3$)	Average Daily 1-hr Maximum PM_{10} ($\mu g/m^3$)
Atascadero	20.1	17.5	17.9	41.6
Santa Maria	22.8	30.0	30.8	45.6
Lompoc	14.5	14.8	16.1	30.0
Lancaster	30.3	30.8	35.9	77.5
San Dimas	28.0	32.4	32.8	50.7
Upland	37.9	41.4	41.7	69.6
Long Beach	31.3	35.1	31.7	61.3
Mira Loma	55.2	52.4	54.6	116.6
Riverside	33.6	36.8	38.6	67.9
Lake Elsinore	30.5	27.7	30.8	59.2
Lake Arrowhead	22.4	34.3	33.9	63.5
Alpine	22.3	27.7	26.6	39.1
Average	29.1	31.7	32.6	60.2

Table 3-8. Summary of additional 1994 annual average PM_{10} exposure metrics.

Community	Hours Per Month with $[PM_{10}]$ $>30\ \mu g/m^3$	Hours Per Month with $[PM_{10}]$ $>50\ \mu g/m^3$	Hours Per Month with $[PM_{10}]$ $>100\ \mu g/m^3$	Hours Per Month with $[PM_{10}]$ $>150\ \mu g/m^3$	$\mu g/m^3$-hours[a] Per Month with $[PM_{10}]$ $>30\ \mu g/m^3$	$\mu g/m^3$-hours[a] Per Month with $[PM_{10}]$ $>50\ \mu g/m^3$	$\mu g/m^3$-hours[a] Per Month with $[PM_{10}]$ $>100\ \mu g/m^3$	$\mu g/m^3$-hours[a] Per Month with $[PM_{10}]$ $>150\ \mu g/m^3$
Atascadero	103.7	17.1	1.8	0.3	4433	1197	256	61
Santa Maria	165.5	49.4	4.5	1.5	8116	3599	617	247
Lompoc	47.1	4.0	0.6	0.3	1854	292	82	38
Lancaster	274.1	89.7	11.8	3.8	14037	6844	1745	793
San Dimas	256.1	69.9	0.7	0	11577	4388	74	0
Upland	360.5	159.9	12.9	4.3	19736	11764	2101	1086
Long Beach	298.2	81.4	5.1	1.1	13887	5534	659	208
Mira Loma	473.3	317.8	76.7	17.9	33688	27434	10418	3394
Riverside	330.3	143.9	10.2	2.8	17630	10250	1565	696
Lake Elsinore	288.0	102.4	4.0	0.3	14086	6755	492	51
Lake Arrowhead	190.7	70.5	5.2	0.9	9684	4923	679	183
Alpine	136.1	19.3	0.6	0.3	5629	1178	89	45
Average	243.6	93.8	11.2	2.8	12863	7013	1564	566

[a] Weighted sum of the hours above the threshold concentration multiplied by the concentration.

Table 3-9. Annual average ambient gaseous acid and $PM_{2.5}$ concentrations in the 12 communities in 1994 measured by the Two-Week Sampler.

Community[a]	Gaseous Acid Concentrations (ppb)				$PM_{2.5}$ Concentrations ($\mu g/m^3$)				
	Hydrochloric Acid[b]	Nitric Acid	Formic Acid[c]	Acetic Acid[c]	Mass[d]	Nitrate	Ammonium	Chloride[e]	Sulfate
Atascadero	0.31	0.98	0.72	1.96	7.62	1.99	0.80	0.11	0.73
Santa Maria	0.48	0.84	0.50	1.11	6.70	1.42	0.66	0.17	1.28
Lompoc[f]	0.53	0.49	0.31	0.94	7.28	0.84	0.44	0.30	1.08
Lancaster[g]	0.33	1.97	1.28	3.67	9.25	2.71	1.34	0.00	0.95
San Dimas	0.76	4.20	2.87	5.05	22.13	8.28	3.41	0.04	2.85
Upland	0.81	3.88	3.10	5.17	24.01	9.24	3.72	0.02	2.54
Long Beach	0.98	2.51	1.74	3.06	16.28	5.90	2.71	0.01	2.77
Mira Loma[h]	0.51	2.59	1.91	5.54	31.54	13.54	4.90	0.16	2.93
Riverside	0.57	3.16	1.69	4.18	25.52	10.83	4.35	0.05	2.51
Lake Elsinore[i]	0.62	2.69	1.34	3.80	13.39	3.94	2.08	0.02	2.44
Lake Arrowhead[j]	0.54	2.95	0.92	2.85	11.11	3.44	1.49	0.01	1.21
Alpine[k]	0.72	2.07	1.19	2.97	9.18	2.00	1.19	0.01	2.10
Average	0.58	2.33	1.50	3.33	15.3	5.33	2.26	0.08	1.92

[a] All concentrations are blank-corrected and include backup filter concentrations when appropriate.

[b] A significant number of values were below the limit of detection. However, all values are included in the average.

[c] These are upper limit acetic acid concentrations. No collocated organic acids data were collected during Periods 1-3 (December 15 to January 25); organic acids data were not collected at Upland during Period 3 (January 12 to 26).

[d] Mass excludes Period 4 (suspect, January 26 to February 9), Periods 5 and 6 (invalid, February 10 to March 9). Mass data include the mass of nitrate and ammonium collected on the backup filter.

[e] Backup chloride not included. Most values were below the limit of detection. Missing Teflon chloride at Lancaster Periods 8 and 9 (March 23 to April 20), Lake Arrowhead Period 9 (April 6 to 20). Chloride data collected at Lake Elsinore during Period 12 (May 18 to June 2) were invalidated. The chloride concentration of more than 25 $\mu g/m^3$ was three orders of magnitude higher than other measurements and was not due to any laboratory problems.

[f] Period 21 at Lompoc was suspect and not used

[g] No data for Period 15 at Lancaster due to pump failure.

[h] No data for Period 20 at Mira Loma due to pump failure.

[i] No data for Period 8 at Lake Elsinore due to pump failure, and Period 9 was invalidated due to pump problems that resulted in a short sample.

[j] Data collection began for Period 7 (March 10).

[k] Data collection began for Period 6 (February 24).

Table 3-10. Precision of the two-week sampler based on collocated measurements.

Pollutant	Lower Quantifiable Limit	Pooled Coefficient of Variance (%)
$PM_{2.5}$ Mass	5.5 $\mu g/m^3$	11.1
$PM_{2.5}$ Nitrate	0.15 $\mu g/m^3$	8.6
$PM_{2.5}$ Ammonium	0.03 $\mu g/m^3$	7.1
$PM_{2.5}$ Chloride	0.31 $\mu g/m^3$	N/A
$PM_{2.5}$ Sulfate	0.45 $\mu g/m^3$	12.1
Hydrochloric Acid	1.54 ppb	N/A
Nitric Acid	0.09 ppb	11.1[a]
Formic Acid	0.18 ppb	10.8
Acetic Acid	0.49 ppb	5.1

N/A - There were insufficeint numbers of samples above the LQL to calculate the precision.
[a] One outlier was removed.

Table 3-11. Normalized deviations from the mean ambient air quality conditions in the 12 communities for 1986-1990, 1993, and 1994. The 12-community mean and standard deviation are listed at the bottom of the table.

Community	Ozone (Average 1-hr Daily Max)			NO_2 (24-hr Average)			PM_{10} (24-hr Average)			$PM_{2.5}$ (24-hr)
	1986-1990[a]	1993[a]	1994	1986-1990[a]	1993[a]	1994	1986-1990[b]	1993[b]	1994[c]	1994[d]
Atascadero	-0.67	-0.79	-0.80	-1.28	-1.05	-0.58	-1.25	-1.18	-0.84	-0.95
Santa Maria	-1.85	-1.27	-1.42[e]	-1.32	-1.33	-1.33[e]	-1.24	-1.06	-0.65[e]	-1.07
Lompoc	-1.34	-1.27	-1.16	-1.12	-1.33	-1.33	-1.10	-1.31	-1.36	-1.00
Lancaster	-0.14	-0.11	-0.35	-0.56	-0.51	-0.14	0.21	-0.66	0.12	-0.75
San Dimas	1.34	1.45	0.78	1.19	1.31	1.11	0.63	0.36	-0.11	0.84
Upland	0.70	0.65	0.31	1.48	1.01	1.51	1.09	1.12	0.91	1.07
Long Beach	-1.23	-0.99	-1.22	1.50	0.94	1.02	-0.19	-0.42	0.22	0.12
Mira Loma	0.83	0.59	0.39	0.58	0.81	0.63	1.55	1.31	2.45	2.00
Riverside	0.83	1.01	0.65	0.58	0.70	0.86	1.55	1.70	0.44	1.26
Lake Elsinore	0.32	0.45	0.40	-0.29	-0.57	-0.09[f]	0.30	0.90	0.15[g]	-0.24
Lake Arrowhead	0.99	1.36	1.93[h]	-0.12	1.02	-1.00[h]	-0.74	-0.24	-0.61[h]	-0.52
Alpine	0.23	-1.10	0.48[e,h]	-0.64	-1.00	-0.66[e,h]	-0.79	-0.51	-0.73[e,h]	-0.76
Average[i]	75.0	62.4	67.0	25.1	25.3	21.6	53.4	41.9	29.2	15.3
Standard Deviation[i]	24.2	17.8	21.1	13.2	11.0	13.0	20.4	13.2	10.6	8.08

[a] Actual and interpolated ozone and NO_2 data.
[b] Actual and interpolated HiVol measurements.
[c] TEOM measurements.
[d] Two-Week Sampler measurements.
[e] Missing data for October through December.
[f] Missing data for April and May.
[g] Missing data for January.
[h] Missing data for October through December.
[i] O_3 and NO_2 concentrations are in ppb and the PM_{10} concentrations are in µg/m3.

Table 3-12. Deviations of $PM_{2.5}$, inorganic acid, and organic acid ambient concentrations from the mean concentrations in the 12 communities in 1994. The mean and standard deviation of the annual concentrations from the 12 communities are listed at the bottom of the table. Pre-study estimates of deviations of inorganic acid concentrations from the Southern California mean are also listed.

Community	1994 $PM_{2.5}$ Mass	Pre-Study Inorganic Acids[a]	1994 Inorganic Acids[b]	1994 Organic Acids[a]
Atascadero	-0.95	-1.1	-1.30	-0.92
Santa Maria	-1.07	-1.1	-1.28	-1.16
Lompoc	-1.00	-1.1	-1.51	-1.31
Lancaster	-0.75	1.5	-0.51	0.19
San Dimas	0.84	1.3	1.57	1.40
Upland	1.07	1.5	1.35	1.54
Long Beach	0.12	0.7	0.42	0.13
Mira Loma	2.00	-0.9	0.11	1.21
Riverside	1.26	-0.9	0.60	0.54
Lake Elsinore	-0.24	0.4	0.28	0.27
Lake Arrowhead	-0.52	0.5	0.42	-0.29
Alpine	-0.76	-0.8	-0.13	-0.11
Average[c]	15.33	-	2.96	4.82
Standard Deviation[c]	8.08	-	1.28	2.31

[a] Nitric acid and hydrochloric acid.

[b] Formic and acetic acid.

[c] Acid concentrations are given in ppb; $PM_{2.5}$ mass concentrations are given in $\mu g/m^3$.

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Table 3-13. Ranking of deviations from the mean ambient air quality conditions in the 12 communities for 1986-1990, 1993, and 1994.

Community	Ozone Ranking				NO_2 Ranking			PM_{10} Ranking			$PM_{2.5}$ Ranking
	Annual 1986-1990[a]	Annual 1993[a]	Annual 1994	May-Sept 1994	Annual 1986-1990[a]	Annual 1993[a]	Annual 1994	Annual 1986 1990[b]	Annual 1993[b]	Annual 1994[c]	Annual 1994[d]
Atascadero	low	low	low	low	low	low	low	low	low	low	low
Santa Maria	low	low	low	low	low	low	low	low	low	low	low
Lompoc	low	low	low	low	low	low	low	low	low	low	low
Lancaster	mod[e]	mod	mod	mod	low	low	mod	mod	low	mod	low
San Dimas	high	high	high	high	high	high	high	high	mod	mod	high
Upland	high	high	mod	high	high	high	high	high	high	high	high
Long Beach	low	low	low	low	high	high	high	mod	mod	mod	mod
Mira Loma	high	high	mod	high	high	high	high	high	high	high	high
Riverside	high	high	high	high	high	high	high	high	high	mod	high
Lake Elsinore	mod	mod	mod	mod	mod	low	mod	mod	high	mod	mod
Lake Arrowhead	high	high	high	high	mod	high	low	low	mod	low	low
Alpine	mod	low	mod	mod	low	low	low	low	low	low	low

[a] Actual and interpolated ozone and NO_2 data.
[b] Actual and interpolated HiVol measurements.
[c] TEOM measurements.
[d] Two-Week Sampler measurements.
[e] mod = moderate.

Table 3-14. Relative ranking of inorganic acid and organic acid ambient concentrations from the mean concentrations in the 12 communities in 1994.

Community	Pre-Study Inorganic Acids[a]	1994 Inorganic Acids[a]	1994 Organic Acids[b]
Atascadero	low	low	low
Santa Maria	low	low	low
Lompoc	low	low	low
Lancaster	high	low	mod
San Dimas	high	high	high
Upland	high	high	high
Long Beach	high	mod	mod
Mira Loma	low	mod	high
Riverside	low	high	high
Lake Elsinore	mod	mod	mod
Lake Arrowhead	mod	mod	mod
Alpine	low	mod	mod

[a] Nitric acid and hydrochloric acid.

[b] Formic and acetic acid.

[c] mod = moderate.

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Table 3-15. Historical student resident locations in California.

29 Palms Marine Base	Boyle Heights	Colton
Adelanto	Brawley	Commerce
Agoura	Brea	Compton
Agoura Hills	Brentwood	Concord
Alhambra	Bridgeport	Corning
Alpine	Buellton	Corona
Alta Loma	Buena Park	Coronado
Altadena	Burbank	Costa Mesa
Alturas	Butte City	Coto de Caza
Anaheim	Cabazon	Covina
Anaheim Hills	California City	Crenshaw
Apple Valley	Calimesa	Crest
Aqua Fria	Calipatria	Crest Park
Arcadia	Camarillo	Crestline
Arleta	Cambria	Creston
Arlington	Campbell	Crowley Lake
Armona	Campo	Culver City
Arrowbear Lake	Canoga Park	Cypress
Arroyo Grande	Canyon Country	Daggett
Artesia	Canyon Lake	Dana Point
Atascadero	Capistrano Beach	Danville
Atwater	Capitola	Davis
Azusa	Cardiff By the Sea	Dehesa Valley
Bakersfield	Carlsbad	Del Rosa
Baldwin Park	Carpinteria	Descanso
Banning	Carson	Desert Hot Springs
Barstow	Casa de Oro	Devore
Beale AFB	Casmalia	Diamond Bar
Beaumont	Castaic	Dinuba
Bell	Castle AFB	Downey
Bell Gardens	Catalina	Duarte
Bellflower	Cathedral City	Earlimart
Bermuda Dunes	Cayucos	East Los Angeles
Beverly Hills	Cedar Glen	Edgemont
Big Bear Lake	Cedar Pines Park	Edwards
Big Timber	Cerritos	Edwards AFB
Bishop	Chatsworth	El Cajon
Bixby Hills	Cherry Valley	El Centro
Bloomington	Chico	El Cerrito
Blue Jay	Chino	El Monte
Blythe	Chino Hills	El Rio
Bonita	Chula Vista	El Segundo
Boron	Citrus Heights	El Sereno
Borou	Claremont	El Toro
Boulevard	Clovis	Elverta

Table 3-15. Historical student resident locations in California.

Encinitas	Hesperia	Lakewood
Escondido	Hickman	Lancaster
Etawanda	Highgrove	Lawndale
Eureka	Highland	Lemon Grove
Fallbrook	Highland Park	Lemoore
Fillmore	Hollywood	Leona Valley
Firebaugh	Huntington Beach	Littlerock
Fletcher Hills	Huntington Harbor	Livermore
Flinn Springs	Huntington Park	Lodi
Fontana	Idyllwild	Loma Linda
Forest Falls	Imperial Beach	Lompoc
Foresthill	Independence	Long Beach
Fort Jones	Indio	Loomis
Fort Ord	Inglewood	Los Alamitos
Foster City	Ione	Los Altos
Fountain Valley	Irvine	Los Angeles
Frazier Park	Jacumba	Los Osos
Fremont	Jamul	Lost Hills
Fresno	Japatul Valley	Lucern Valley
Fullerton	Julian	Lytle Creek
Galt	Junction City	Madera
Garden Grove	Kensington	Malibu
Gardena	La Canada Flintridge	Mammoth Lakes
Georgetown	La Costa	Manteca
Geyserville	La Crescenta	Marina Del Rey
Gilroy	La Habra	Mariposa
Glen Avon	La Habra Heights	Mead Valley
Glendale	La Jolla	Mecca
Glendora	La Mesa	Menifee
Goleta	La Mirada	Menlo Park
Gonzales	La Palma	Merced
Granada Hills	La Pauinta	Midway City
Grand Terrace	La Puente	Milpitas
Grass Valley	La Quinta	Mira Loma
Grover Beach	La Verne	Mira Mesa
Grover City	Laguna Beach	Mission Hills
Guadalupe	Laguna Hills	Mission Viejo
Guatay	Laguna Niguel	Modesto
Hacienda Heights	Lake Arrowhead	Mojave
Harbison Canyon	Lake Elizabeth	Mono City
Harbor City	Lake Elsinore	Monrovia
Hawthorne	Lake Isabella	Montclair
Hayward	Lake Los Angeles	Montebello
Hemet	Lake Matthews	Montecito
Hermosa Beach	Lakeside	Monterey Park

Table 3-15. Historical student resident locations in California.

Montrose	Pauma Valley	Salinas
Moorpark	Pedley	San Bernardino
Moreno Valley	Penn Valley	San Clemente
Morro Bay	Perris	San Diego
Mountain View	Phelan	San Dimas
Murrieta	Phillips Ranch	San Fernando
National City	Pico Rivera	San Francisco
Newbury Park	Pine Valley	San Gabriel
Newhall	Placentia	San Jacinto
Newport Beach	Placerville	San Joaquin
Nipomo	Point Arena	San Jose
Norco	Pomona	San Juan Bautista
North Highlands	Port Hueneme	San Juan Capistrano
North Hollywood	Porterville	San Luis Obispo
North Park	Potrero	San Miguel
Northridge	Poway	San Pedro
Norwalk	Quail Valley	San Ramon
Novato	Quartz Hill	Sanger
Nuevo	Quincy	Santa Ana
Oakland	Ramona	Santa Barbara
Oceano	Rancho California	Santa Cruz
Oceanside	Rancho Cucamonga	Santa Fe Springs
Ojai	Rancho Palos Verdes	Santa Margarita
Ontario	Redding	Santa Maria
Orange	Redlands	Santa Monica
Orange City	Redondo Beach	Santa Paula
Orcutt	Reseda	Santa Rosa
Oro Grande	Rialto	Santa Ynez
Oroville	Richmond	Santee
Oxnard	Ridgecrest	Sanysidro
Pacific Beach	Rim Forest	Saugus
Pacifica	Rio Linda	Scotts Valley
Pacoima	Riverside	Seal Beach
Pala	Rodeo	Seaside
Palm Desert	Rohnert Park	Sepulveda
Palm Springs	Romoland	Sherman Oaks
Palmdale	Rosamond	Sierra Madre
Palos Verdes Estates	Rosemead	Signal Hill
Panorama City	Roseville	Simi Valley
Paradise	Rossmoor	Solvang
Paramount	Rowland Heights	South El Monte
Parkfield	Rubidoux	South Gate
Pasadena	Running Springs	South Pasadena
Paso Robles	Sacramento	Spring Valley
Patterson	Salida	Stanford

Table 3-15. Historical student resident locations in California.

Stanton	Ukiah
Stockton	University City
Studio City	Upland
Summerland	Vacaville
Sun City	Valinda
Sun Valley	Vallejo
Sunland	Valley center
Sunnymead	Van Nuys
Sylmar	Vandenberg AFB
Taft	Ventura
Tahoe City	Victorville
Tarzana	Visalia
Tehachapi	Vista
Temecula	Walker
Temple City	Walnut
Templeton	Walnut Creek
Terminal Island	Waterford
Terra Bella	West Covina
Thornton	Westlake Village
Thousand Oaks	Westminster
Tierra Santa	Whittier
Torrance	Wildomar
Trabuco Canyon	Wilmington
Travis AFB	Woodland
Treasure Island	Woodland Hills
Trona	Wrightwood
Truckee	Yorba Linda
Tujunga	Yucaipa
Tustin	Yucca Valley
Twin Peaks	

Table 3-16. Historical student residence locations in states other than California.

Anchorage, AK	Pocatello, ID	Bozeman, MT	El Paso, TX
Fairbanks, AK	Twin Falls, ID	Helena, MT	Houston, TX
Juneau, AK	Boise, ID	Kalispell, MT	Logan, UT
Little Rock, AR	Coeur D'Alene, ID	Raleigh, NC	Ogden, UT
Kingman, AZ	Idaho City, ID	Fargo, ND	Provo, UT
Lake Havasau City, AZ	Champaign, IL	Omaha, NE	Salt Lake City, UT
Lancaster, AZ	Chicago, IL	Passaic, NJ	Charlottesville, VA
Mesa, AZ	Downers Grove, IL	Edison, NJ	Culpeper, VA
Phoenix, AZ	South Bend, IN	Albuquerque, NM	Burlington, VT
Tombstone, AZ	Indianapolis, IN	Las Vegas, NV	Puyallup, WA
Tucson, AZ	Abilene, KS	Reno, NV	Seattle, WA
Yuma, AZ	Fort Knox, KY	Carson City, NV	Spokane, WA
Thornton, CO	Lake Charles, LA	New York, NY	Tacoma, WA
Colorado Springs, CO	New Orleans, LA	Patchogue, NY	Kewaunee-Green Bay, WI
Denver, CO	Shreveport, LA	Rochester, NY	Milwaukee, WI
Fort Collins, CO	Cape Cod, MA	Saranac Lake, NY	Casper, WY
Danbury, CT	Silver Spring, MD	Studio City, NY	Cheyenne, WY
Hartford, CT	Annapolis, MD	Syracuse, NY	Philadelphia, PA
Miami, FL	Fredericksburg, MD	Binghamton, NY	Myrtle Beach, SC
Ocala, FL	Gaithersburg, MD	Dix Hills, NY	Rapid City, SD
Panama City, FL	Bath, ME	Youngstown, OH	Memphis, TN
Pensacola, FL	Muskegon, MI	Cincinnati, OH	Lubbock, TX
Pinellas Park, FL	Bay City, MI	Cleveland, OH	Paris, TX
Sarasota, FL	Detroit, MI	Columbus, OH	Plano, TX
Tampa, FL	East Lansing, MI	Oklahoma City, OK	San Antonio, TX
Fort Lauderdale, FL	Minneapolis, MN	Elk City, OK	Waco, TX
Jacksonville, FL	Minneapolis/Saint Paul, MN	Enid, OK	Amarillo, TX
Atlanta, GA	Saint Paul, MN	Klamath Falls, OR	Austin, TX
Hilo, HI	Saint Louis, MO	Portland, OR	Dallas, TX
Honolulu, HI	Independence, MO	Bend, OR	
Kailua, HI	Missoula, MT	Corvallis, OR	
Kailua Kona, HI	Billings, MT	Eugene, OR	

Table 3-17. Historical student residence locations in foreign countries.

Country, City	Country, City	Country, City
Algeria, Mostaganem	Guatemala, Villa Nueve	Mexico, Tijuana
Argentina, Buenos Aires[a]	Hong Kong, Kowloon	Mexico, Urequro Mich
Argentina, Puerto Madryn	India, Bombay[a]	Mexico, Veracruz
Belize, Belize City	India, Hisar	Mexico, Yurecuaro
Bulgaria, Sofia	Indonesia, Jakarta[a]	Mexico, Zihuatancio
Cambodia, Battambang	Iran, Tehran	Philippines, Angeles City
Canada, Calgary	Italy, Brindisi	Philippines, Blank
Canada, Curve Lake	Italy, Fondi	Philippines, Cavite
Canada, Montreal	Italy, Italy	Philippines, Clark AFB
Canada, Ottawa	Japan, Misawa	Philippines, Olongato City
Denmark, Koldby	Japan, Misawa AFB	Ohilippines, Roxas City, Capiz
El Salvador, San Salvador	Japan, Okinawa	Philippines, Sta Barbara
England, Chichsands	Japan, Tokyo[a]	Philippines, San Miguel
England, Cambridge	Japan, Yokota AB	Phillipines, Fairview, Quezon City
England, Ipswich	Kenya, Nairobi	Phillipines, Imus, Cavite
England, London[a]	Korea, Bu-Chun	Phillipines, Manila[a]
England, Lakenheath AFB	Korea, Seoul[a]	Portugal, Azores
England, Mildenhall	Mexico, Apatzingan	Puerto Rico, Fajardo
England, Surrey	Mexico, Buadalajora	Puerto Rico, San Juan
England, Woodbridge	Mexico, Chihuahua	Salvador, Yan
France, Paris	Mexico, Ciudad	Saudi Arabia, Dhahran
Germany, Berlin	Mexico, Cotija	Saudi Arabia, Riyadh
Germany, Hahn	Mexico, Ensenada	Saudi Arabia, Yanbu Al Sinayah
Germany, Hahn AFB	Mexico, Guadalajara	Spain, Barcelona
Germany, Ramstein AFB	Mexico, Guadalaga	Spain, Bilbao
Germany, Stuttgart	Mexico, Guanajuaro	Spain, Competa
Germany, Schweinfurt	Mexico, Jalisco	Spain, Madrid
Germany, Sembach AFB	Mexico, Leon, Guanajuato	Spain, Palma, Majorca
Germany, Spangdohlem	Mexico, Mazatlan	Spain, Torrejon
Germany, Weisbaden	Mexico, Mexico Destita Federal	Switzerland, Muolen
Germany, Zwiebrucker	Mexico, Morelia	Syria, Damascus
Germany, Frankfurt	Mexico, Mazatlen Sin.	Taiwan, Taipei
W. Germany, Gelsenkirehen	Mexico, Mexico City[a]	Thailand, Bangkok[a]
W. Germany, Ramstein	Mexico, Michoucan	Uae, Al Aing
W. Germany, Rfalzdorf	Mexico, Oaxaca	Vietnam, Ho Chi Minh City
W. Germany, Teimen	Mexico, Pueblo	Vietnam, Nha Trang
W. Germany, Weismoor	Mexico, San Jose	Vietnam, Qui Nhon
Guam, Agana Guam	Mexico, Tangancicuaro Mich	Vietnam, Siagon
Guam, Anderson AFB	Mexico, Tepic Nayarit	Zaire, Lubumbash
Guam, Yigo		

[a] A summary of air quality is available from WHO (1992).

Table 3-18. Indoor/outdoor ozone ratios in schools stratified by building and ventilation system type.

Ventilation System	Conventional Building		Portable Building
	With Carpet	Without Carpet	With Carpet
Central Air Conditioning	0.17 ± 0.17 (n=138)	0.20 ± 0.11 (n=14)	0.10 ± 0.10 (n=60)
No Air Conditioning or AC not Operating	0.38 ± 0.26 (n=22)	0.28 ± 0.16 (n=28)	0.12 ± 0.10 (n=6)
Swamp Cooler	0.30 ± 0.16 (n=25)	0.37 ± 0.06 (n=4)	none

Overall Mean I/O Ratio = 0.19 ± 0.17

Table 3-19. Sampling locations, characteristics, and periods for the continuous ozone measurements in school classrooms.

Community/School/Classroom	Characteristics	Monitoring Period
Mira Loma, Jurupa Valley High School, Room BF	Portable building, normal ceiling height, air conditioned, carpeted floors and fabric walls.	Oct. 20, 1993 to May 10, 1994
Lake Arrowhead, Rim of the World High School, Room DX	Conventional building, normal ceiling height, no air conditioning, carpeted floors or walls.	May 16, 1994 to June 23, 1994
Lake Arrowhead, Rim of the World High School, Room DW	Conventional building, high ceiling height, no air conditioning, tile floors, and painted walls.	May 16, 1994 to June 23, 1994
Lompoc, Cabrillo High School, Room AS	Conventional building, normal ceiling height, no air conditioning, no carpeted floors and painted walls.	May 13, 1994 to June 10, 1994
Lompoc, Cabrillo High School, Room AR	Conventional building, normal ceiling height, no air conditioning, no carpeted floors and walls.	May 13, 1994 to June 10, 1994

Table 3-20a. Summary of Air Monitoring Results for the Residential Study.

Exposure Variable	Homes Sampled	Mean	Std Dev	Median	Minimum	Maximum
Ozone (ppb)						
Inside	241	13	12	6	5	73
Outside	240	37	19	34	5	108
PM2.5 , ug/m3						
Inside	67	20.9	20.0	13.7	4.2	106.9
Outside	65	16.0	15.0	10.7	2.0	76.8
PM10 , ug/m3						
Inside	88	40.6	36.6	32.9	2.3	294.6
Outside	90	36.3	25.7	29.0	2.2	141.3
HCHO , ug/m3						
Inside	99	11.3	7.4	10.1	0.2	38.8
Outside	18	3.2	2.5	3.2	1.0	10.1
AER	161	0.7	0.5	0.7	0.0	2.5
AERc	161	0.8	0.5	0.7	0.0	2.7

Notes:

1) Concentrations below detection limits for ozone, PM10, and HCHO have been replaced with Limit of Detection values (5 ppb for O3, 2 ug/m3 for PM10, 0.2 ug/m3 HCHO).
2) AER and AERc refer to measurements of home air exchange rates using two methods of home volume calculation; AERc calculation is based on home volume adjusted for volume of furniture and cabinets in the house.
3) AER Limit of Detection determined to be about 1.1/hr ; values larger than this should be considered speculative and prone to error.

Table 3-20b. Summary of Observed Indoor/Outdoor Ratios from the Residential Study.

Exposure Variable	Homes Sampled	Mean	Std Dev	Median	Minimum	Maximum
Ozone, ppb I/O Ratio	239	0.37	0.25	0.20	0.06	1.48
PM2.5 , ug/m3 I/O Ratio	61	2.03	2.99	1.10	0.37	19.96
PM10 , ug/m3 I/O Ratio	87	1.54	1.66	1.05	0.11	10.49
HCHO , ug/m3 I/O Ratio	18	6.01	8.96	3.75	0.01	39.95

Notes:

1) I/O Ratio is in dimensionless units, and refers to the ratio of simultaneous indoor and outdoor pollutant measurements collected in the same home.

Table 3-21. Sampler evaluation ozone chamber studies: January through March 1994, LAREI trailer.

Ozone Exposure (ppb-hr)	Exposure Time in Chamber (min)
25	30
75	90
150	60
300	120
600	120
900	900

Notes:
(1) O_3 generation by mercury grid lamps in ducting and manual operator feedback.
(2) True O_3 defined by average of duplicate Dasibi photometers.
(3) Photometers calibrated to Transfer Standard Dasibi calibrated at SCAQMD.
(4) All experiments performed twice.
(5) All samples prepared and analyzed at Harvard School of Public Health.
(6) One field blank for each sampler type in each experiment.
(7) All generations performed by Ed Avol.

Table 3-22. Chamber conditions for the sampler evaluation ozone chamber studies. January to February experiments--discs vs. 100-μL filters vs. active denuders.

Experiment Number	Temp. (°C) (std. dev.)	RH (%)	Exposure Time (min)	Target O_3 (ppb)	Continuous Ozone Observations	
					obs O_3 (ppb) (std. dev.)	O_3 (ppb-hr)
01A	26.3 (0.2)	49	30	50	54(4)	27
01B	27.1 (0.9)	49	90	50	52.5(3)	79
02A	27.4 (0.0)	49	60	150	152(4)	152
02B	27.3 (0.1)	49	120	150	152(3)	304
03A	23.8(0.1)	51	60	150	151.5(5)	151
03B	24.0(0.3)	51	120	150	151.5(5)	303
04A	25.7(0.2)	44	120	300	306.5(8)	608
04B	25.8(0.1)	44	180	300	306.5(7)	912
05A	25.3(0.3)	44	120	300	304(6)	608
05B	25.5(0.3)	44	180	300	304(6)	912
06A	26.1(0.1)	47	30	50	50(5)	25
06B	26.1(0.1)	47	90	50	49(3)	73

March 1994 Experiments–50-μL vs. 100-μL Filters

Experiment Number	Temp. (°C) (std. dev.)	RH (%)	Exposure Time (min)	Target O_3 (ppb)	Continuous Ozone Observation	
					obs O_3 (ppb) (std. dev.)	O_3 (ppb-hr)
07A	23.6 (0.1)	55	30	50	52(5)	52
07B	24.1 (0.5)	55	90	50	52.5(4)	78
08A	25.3 (0.6)	53	30	50	53(2)	53
08B	24.8 (0.5)	53	90	50	52.5(2)	78
09A	24.2(0.1)	54	60	150	152.5(3)	152
09B	24.3(0.3)	54	120	150	152(4)	304
10A	24.5(0.6)	54	60	150	151.5(4)	151
10B	24.5(0.4)	54	120	150	152.5(3)	305
11A	24.3(0.2)	53	120	300	303(4)	606
11B	24.5(0.3)	53	180	300	302.5(4)	907
12A	24.3(0.4)	53	120	300	299.5(6)	599
12B	24.4(0.4)	53	180	300	299.5(5)	898

Table 3-23. Average blank data for chamber sampler study, February through March, 1994.

Sampler	NO_3 (μg)	Std. Dev.	Percent	O_3 LOD (ppb-hr)
February 1994				
Glass disk	0.11	0.043	39	308
100-μl fiber filter	0.285	0.044	16	81
Active denuder tubes	0.408	0.182	45	55
March 1994				
100-μl fiber filter	0.29	0.064	22	118
50-μl fiber filter	0.201	0.032	16	59

Notes: LOD = Limit of Detection, calculated as three times standard deviation of blank. Flow rates used in calculations: filters @ 10.65 cc/min, for one single-ended Ogawa holder glass disks @ 2.75 cc/min, calculated from chamber data denuder tubes @ ~65 cc/min, based on actual flow measurements.

Table 3-24. Blank levels and Limits of Detection (LOD) for active and passive samplers.

Experiment Date	Analysis Batch	Avg. Active Blank Level NO_3^- (μg/ml)	σ_B Active NO_3^- (μg/ml)	LOD_{Active} O_3 (ppb-hr)	Avg. Passive Blank Level NO_3^- (μg/ml)	σ_B Passive NO_3^- (μg/ml)	$LOD_{Passive}$ O_3 (ppb-hr)
7/19	1	0.0241	0.0072	11	0.1304	0.0142	55
7/19	2	0.0243	0.0098	15	0.1689	0.0213	82
7/21	3	0.0136	0.0016	2	0.1380	0.0223	87
7/21	4	0.0204	0.0081	12	0.1644	0.0201	78
			Mean	10			75

Table 3-25. Comparison of microenvironmental sampler data for 7/19/94.

Location/ Sampler	Active [O_3] (ppb)	Active/Cont. Ratio	Passive [O_3] (ppb)	Passive/Cont. Ratio	Continuous [O_3] (ppb)
First Base #1	103	0.99	163	1.57	104
First Base #2	89	0.86	125	1.20	104
Right Field #1	99	0.95	152	1.46	104
Right Field #2	95	0.91	150	1.44	104
Under Tent #1	97	0.93	118	1.13	104
Under Tent #2	92	0.88	109	1.05	104
Under Tree #1[a]	86	0.83	158	1.52	104
Under Tree #2[a]	104	1.00	101	0.97	104
Mean	96	0.92	135	1.29	104

[a] Sampler moved to right field location during experiment.

Table 3-26. Comparison of microenvironmental sampler data for 7/21/94.

Location/ Sampler	Active [O_3] (ppb)	Active/Cont. Ratio	Passive [O_3] (ppb)	Passive/Cont. Ratio	Continuous [O_3] (ppb)
First Base #1	142	1.03	197	1.43	138
First Base #2	134	0.96	346	2.49	139
Right Field #1	143	1.03	206	1.48	139
Right Field #2	133	0.96	236	1.70	139
Tent #1	125	0.91	180	1.30	138
Tent #2	144	1.04	171	1.24	138
Under Tree #1	117	0.85	185	1.34	138
Under Tree #2	127	0.92	175	1.27	138
Mean	133	0.96	212	1.53	138

Table 3-27. Comparison of active sampler, passive sampler, and continuous ozone monitor data.

Experiment Date	$[O_3]_{average}$ Active Sampler (ppb)	$\sigma_{[O3]}$ Active (ppb)	$[O_3]_{average}$ Passive Sampler (ppb)	$\sigma_{[O3]}$ Passive (ppb)	$[O_3]_{average}$ Continuous Monitor (ppb)	$\sigma_{[O3]}$ Continuous (ppb)
7/19	91	7	113	27	105	2
7/21	136	12	190	25	141	2

Table 3-28. Comparison of averages for active/continuous and passive/continuous ozone ratios.

Experiment Date	$[O_3]_{active}/[O_3]_{cont.}$ Ratio A	$\sigma_{Ratio\ A}$	$[O_3]_{passive}/[O_3]_{cont.}$ Ratio P	$\sigma_{Ratio\ P}$
7/19	0.87	0.069	1.08	0.26
7/21	0.97	0.082	1.29	0.33
Mean	0.92	0.076	1.18	0.30

Table 3-29. Summary of blank levels and LODs for the active sampler.

School	Analysis Batch	Avg. Blank Level, NO_3^- (μg/mL)	sigmab, NO_3^- (μg/mL)	LOD, O_3 (ppb-hr)
Pepper Tree	1	0.146	0.016	4.9
Pepper Tree	2	0.350	0.034	10.3
Pepper Tree	3	0.055	0.014	4.1
Pepper Tree	4	0.072	0.024	7.4
Magnolia	5	0.375	0.016	4.9
Magnolia	6	0.081	0.095	13.6
Magnolia	7	0.245	0.021	6.3
Magnolia	8	0.180	0.025	7.7
Sky Country	9	0.386	0.050	15.2
Sky Country	10	0.276	0.034	10.3
Sky Country	11	0.569	0.026	7.9
Sky Country	12	0.358	0.034	10.2
Troth	13	0.205	0.021	6.4
Troth	14	0.163	0.048	14.5
Troth	15	0.417	0.006	1.7
Mean		0.26	0.03	8.36

Table 3-30. Summary of the measurement schedule, and mean ambient and microenvironmental ozone concentrations during the personal ozone exposure pilot study.

School	Sampling Day	Sampling Time	No. of Students	Ambient Ozone (ppb)	School Outdoor Ozone (ppb)	School Indoor Ozone (ppb)
Pepper Tree	10/6 Thursday	8AM - 6PM	37	39	26	9
Pepper Tree	10/8 Saturday	8AM - 6PM	36	45	-	-
Pepper Tree	10/11 Tuesday	8AM - 2PM	37	33	35	11
Pepper Tree	10/11 Tuesday	2PM - 6PM	34	38	-	-
Magnolia	10/13 Thursday	8AM - 6PM	37	39[a]	22	0
Magnolia	10/15 Saturday	8AM - 6PM	36	37	-	-
Magnolia	10/18 Tuesday	8AM - 2PM	35	37	21	0
Magnolia	10/18 Tuesday	2PM - 6PM	35	40	-	-
Sky Country	10/20 Thursday	8AM - 6PM	39	35	14	0
Sky Country	10/22 Saturday	8AM - 6PM	38	35	-	-
Sky Country	10/25 Tuesday	8AM - 2PM	38	35	21	0
Sky Country	10/25 Tuesday	2PM - 6PM	33	44	-	-
Troth	10/27 Thursday	8AM - 6PM	28	54	47	0
Troth	10/29 Saturday	8AM - 6PM	28	44	-	-
Troth	11/1 Tuesday	8AM - 2PM	27	46	46	0
Troth	11/1 Tuesday	2PM - 6PM	27	53	-	-

[a] There was some missing data at the Mira Loma monitoring site on this day.

Table 3-31. Summary of personal ozone exposure measurments from the pilot study.

School	Sampling Day	Mean Time	Average Exposure (ppb)	Median Exposure (ppb)	Lower Quartile (ppb)	Upper Quartile (ppb)
Pepper Tree	10/6 Thursday	8AM - 6PM	12.7	12.3	11.2	14.7
Magnolia	10/13 Thursday	8AM - 6PM	10.0	9.7	6.4	12.7
Sky Country	10/20 Thursday	8AM - 6PM	13.8	10.9	8.2	13.4
Troth	10/27 Thursday	8AM - 6PM	20.2	20.2	14.0	24.1
Pepper Tree	10/8 Saturday	8AM - 6PM	10.9	9.1	4.9	14.8
Magnolia	10/15 Saturday	8AM - 6PM	5.1	4.3	2.2	6.9
Sky Country	10/22 Saturday	8AM - 6PM	7.1	4.7	0.7	12.2
Troth	10/29 Saturday	8AM - 6PM	10.2	3.4	2.3	10.0
Pepper Tree	10/11 Tuesday	8AM - 2PM	12.7	12.7	10.9	14.5
Magnolia	10/18 Tuesday	8AM - 2PM	6.1	5.8	4.3	8.1
Sky Country	10/25 Tuesday	8AM - 2PM	6.8	6.1	4.8	9.4
Troth	11/1 Tuesday	8AM - 2PM	12.6	12.4	9.9	15.1
Pepper Tree	10/11 Tuesday	2PM - 6PM	17.7	13.8	10.2	25.4
Magnolia	10/18 Tuesday	2PM - 6PM	9.6	8.0	3.3	13.6
Sky Country	10/25 Tuesday	2PM - 6PM	15.8	14.9	7.1	23.0
Troth	11/1 Tuesday	2PM - 6PM	22.6	21.6	17.2	27.5

Table 3-32. Summary of personal exposure model regression results.

Covarites	Data Included[a]	Intercept	Slope	Ratio of Means[b]	R^2
Model Prediction	A	5.81 (P<0.01)	0.39 (P<0.01)	0.76	0.094
Model Prediction	B	4.46 (P<0.01)	0.45 (P<0.01)	0.74	0.18
Model Prediction	C	4.06 (P<0.01)	0.47 (P<0.01)	0.73	0.21
Ambient Concentration	C	-2.53 (P=0.44)	0.34 (P<0.01)	0.28	0.06
Outdoor Fraction	C	5.70 (P<0.01)	16.8 (P<0.01)	33.4	0.13

[a] A: all data, B: all data not listed by field or laboratory staff as suspect, C: all data not listed by field or laboratory staff as suspect and only data with complete time-activity diaries.
[b] Ratio of means of the independent and dependent variables.

Table 3-33. Regression results by sample type including only complete data.

Covariates	Intercept	Slope	Ratio of Means[a]	R^2
Tuesday Morning	3.28 (P<0.01)	0.56 (P<0.01)	1.02	0.44
Tuesday Afternoon	4.58 (P=0.13)	0.61 (P<0.01)	0.58	0.23
Thursday	5.70 (P<0.01)	0.46 (P<0.01)	0.82	0.24
Saturday	-1.30 (P<0.01)	0.48 (P<0.01)	0.57	0.23

[a] Ratio of the mean of the independent and dependent variables.

Table 3-34. Regression results by school for only complete and non-suspect data.

Covariates	Intercept	Slope	Ratio of Means[a]	R^2
Pepper Tree	6.94 (P<0.01)	0.37 (P<0.01)	0.85	0.11
Magnolia	6.95 (P<0.01)	0.046 (P=0.61)	1.53	0.32
Sky Country	4.00 (P=0.01)	0.46 (P<0.01)	1.06	0.24
Troth	5.67 (P=0.09)	0.49 (P<0.01)	0.75	0.15

[a] Ratio of the mean of the independent and dependent variables.

Southern California Children's Health Study
Ambient Air Quality Monitoring Sites

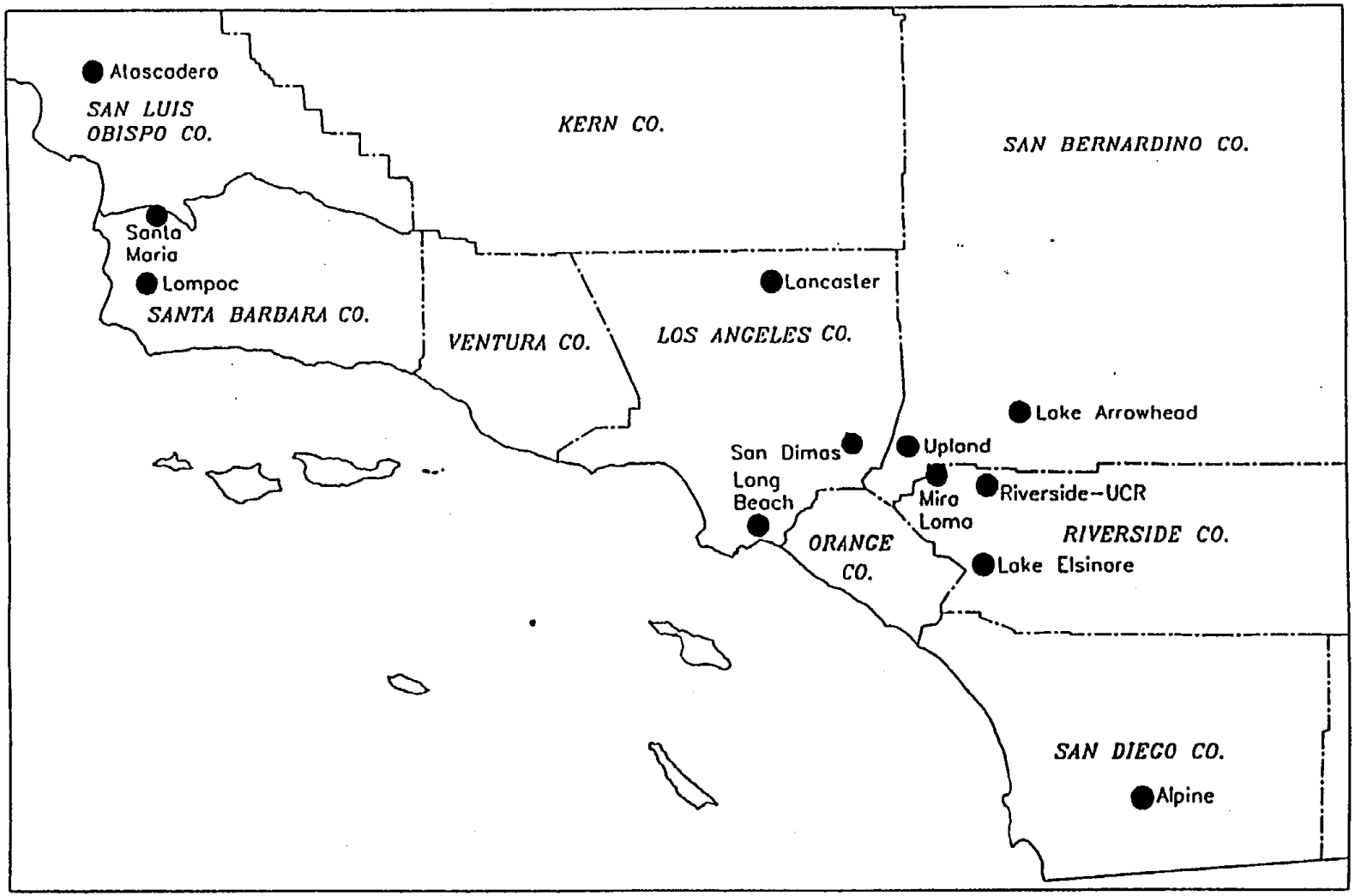


Figure 3-1. Locations of the ambient air monitoring sites.

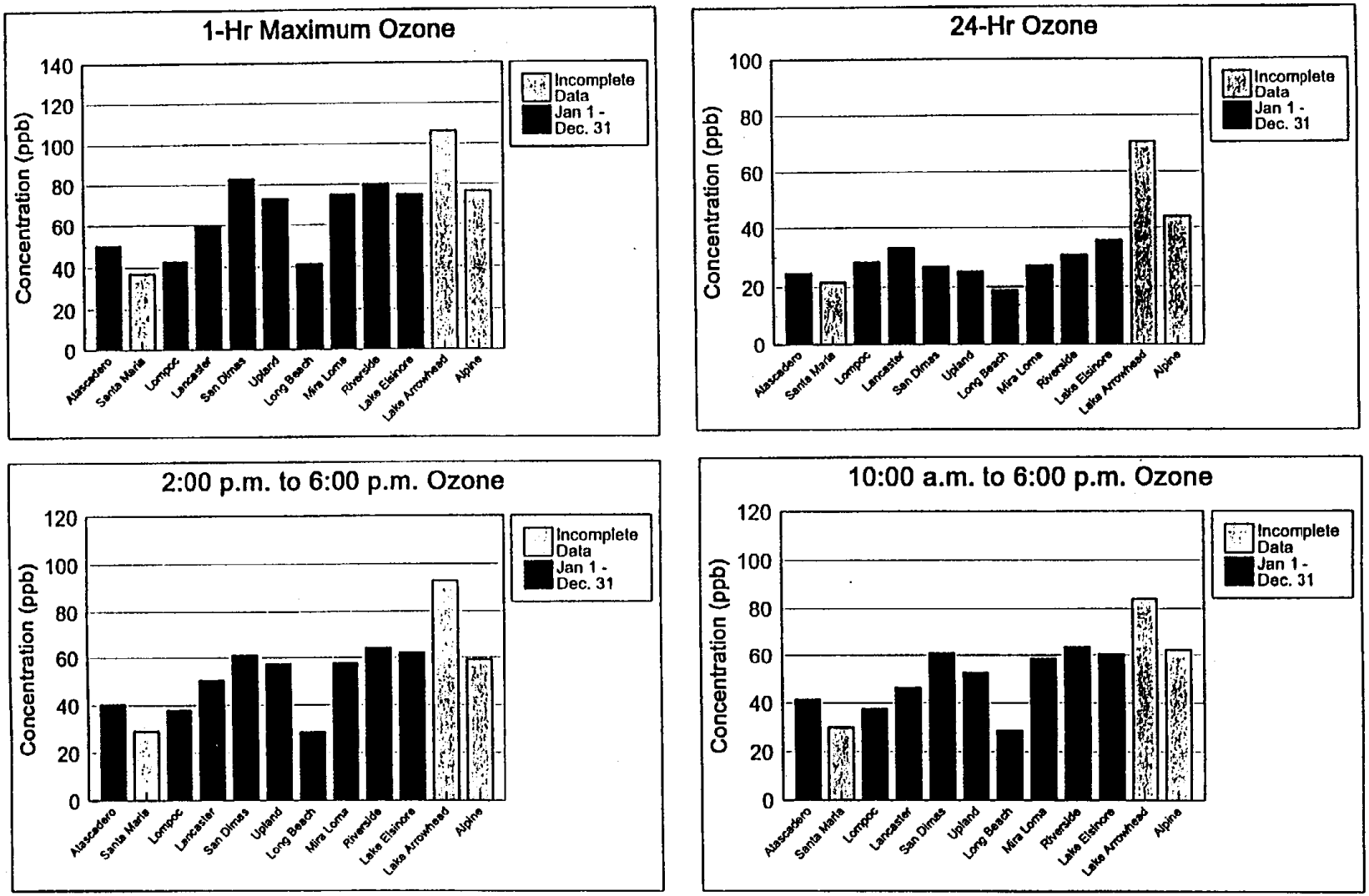


Figure 3-2. Annual average daily 1-hr maximum, 24-hr, 2:00 p.m. to 6:00 p.m., and 10:00 a.m. to 6:00 p.m. ambient ozone concentrations in the 12 communities in 1994.

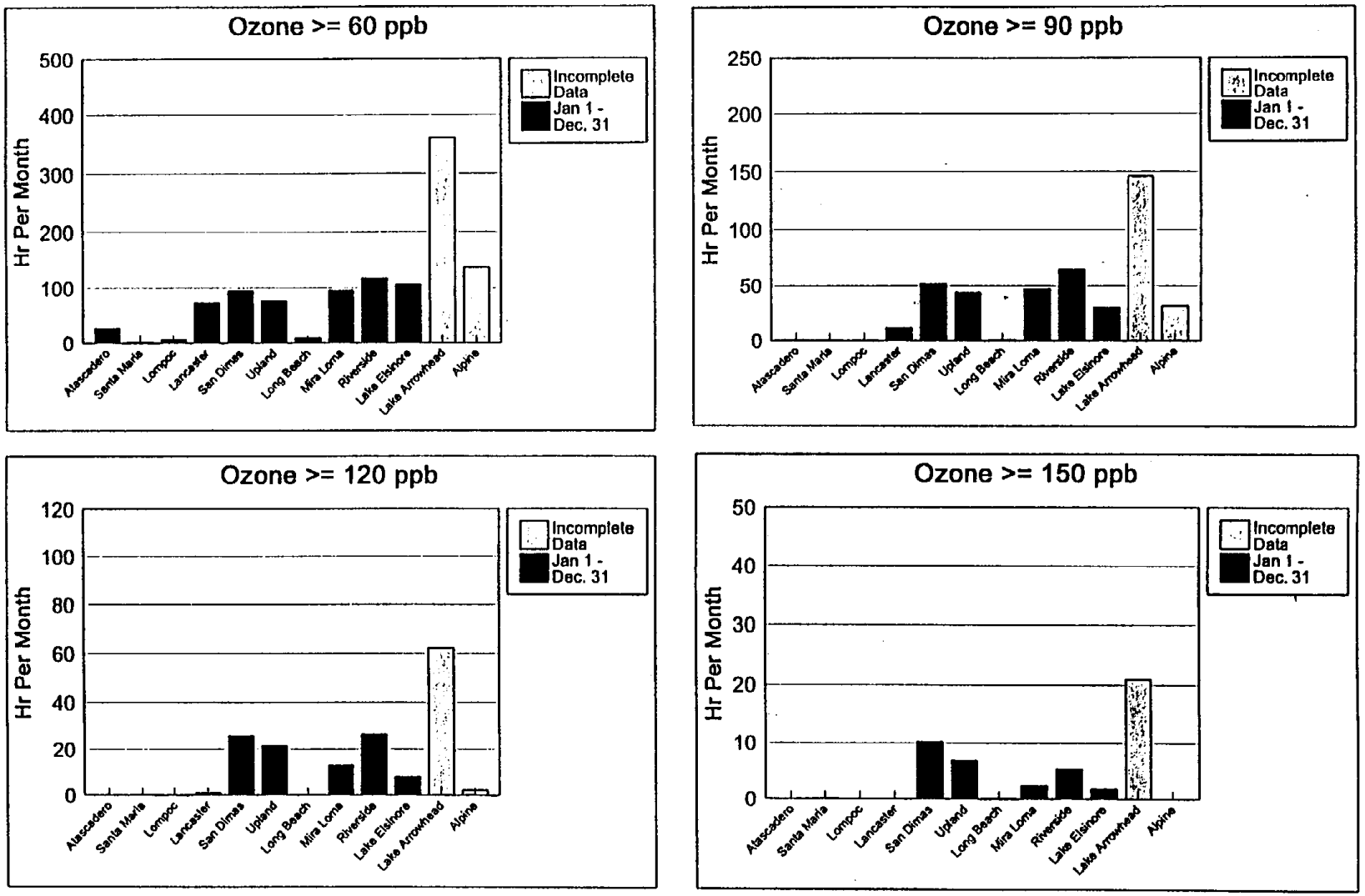


Figure 3-3. Annual average number of hours per month with ambient ozone concentrations equal to or greater than 60, 90, 120, and 150 ppb in the 12 communities in 1994.

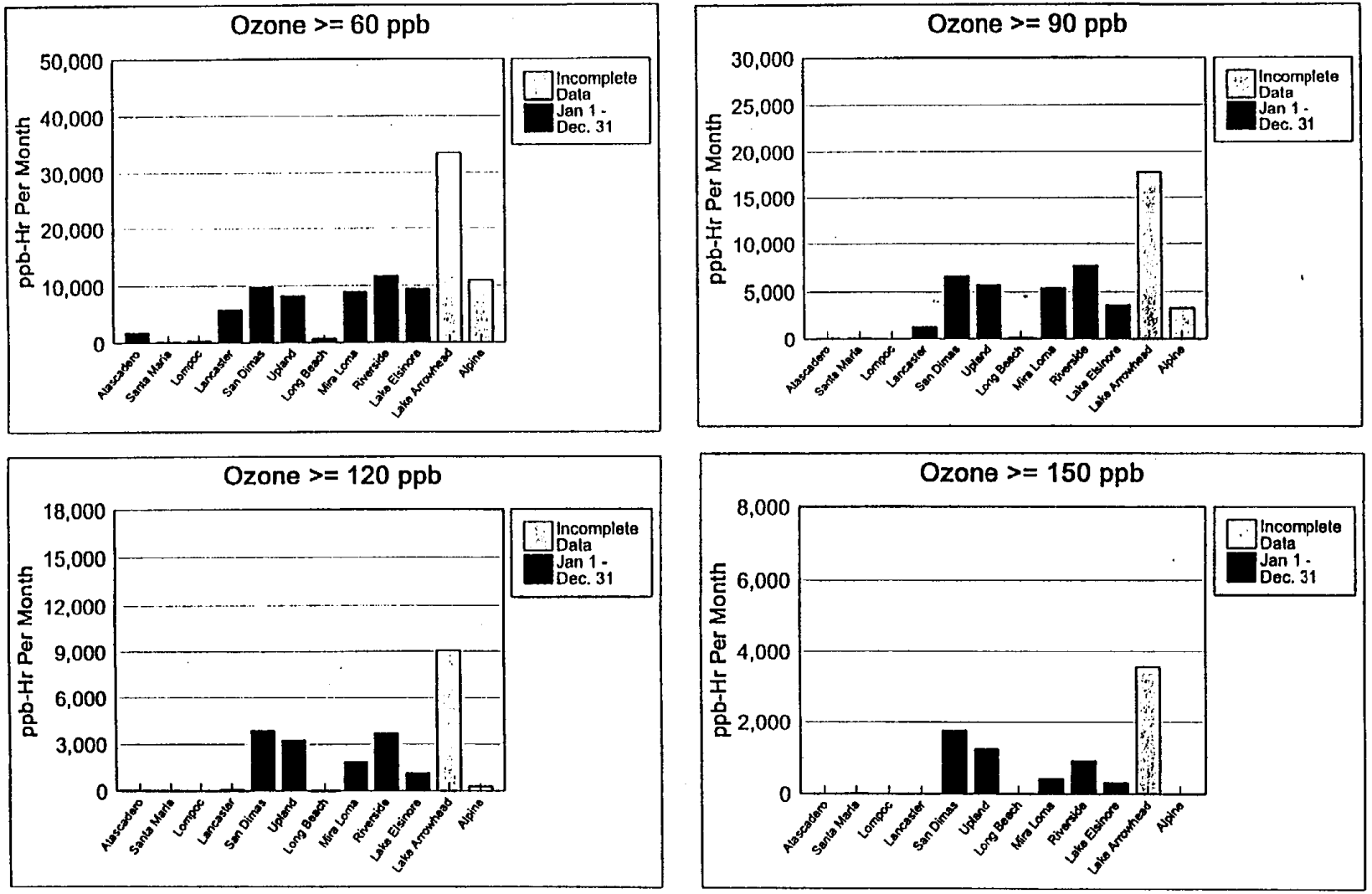


Figure 3-4. Annual average number of concentration-weighted hours per month with ambient ozone concentrations equal to or greater than 60, 90, 120, and 150 ppb in the 12 communities in 1994.

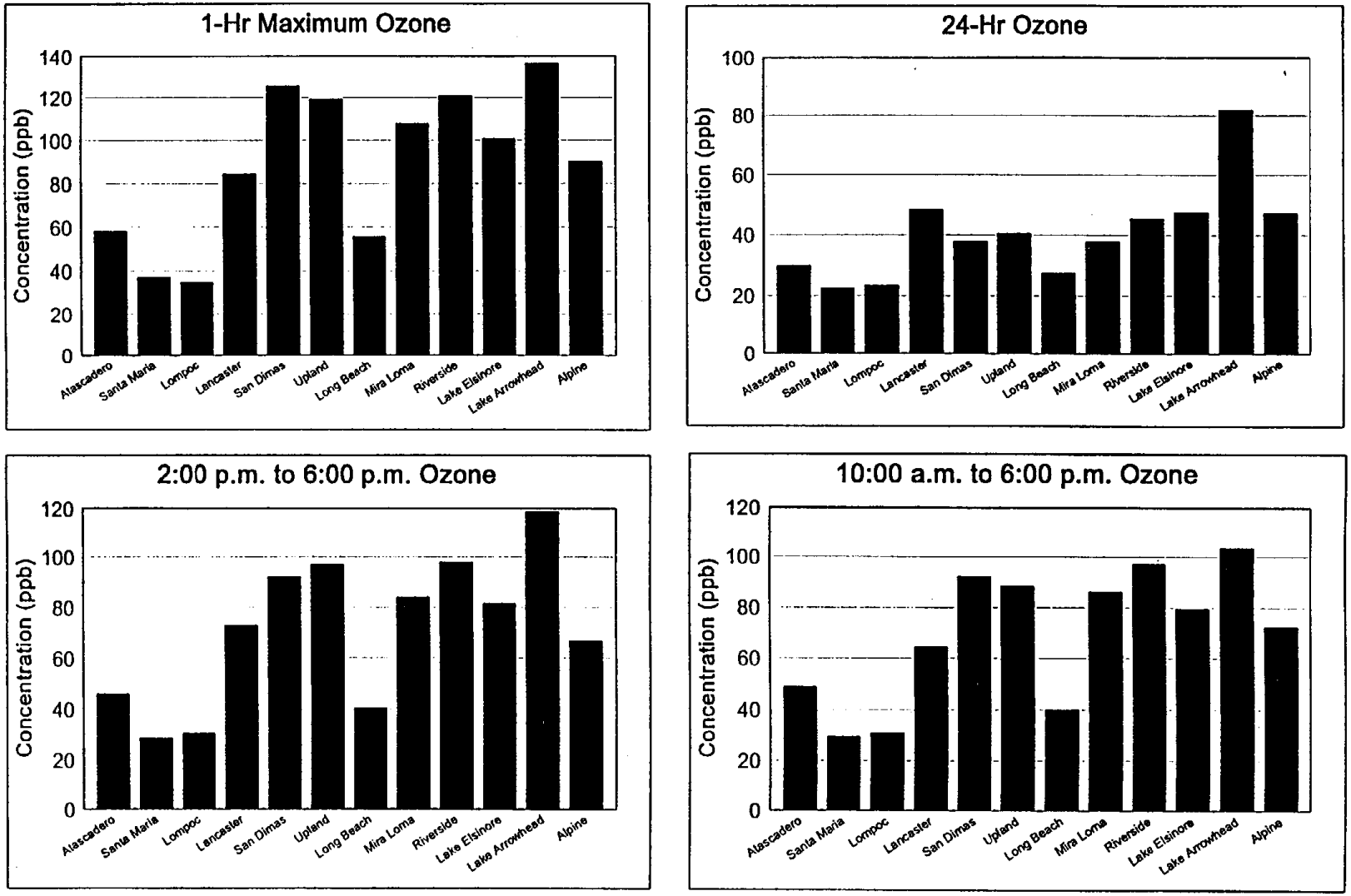


Figure 3-5. Average daily 1-hr maximum, 2:00 p.m. to 6:00 p.m., 10:00 a.m. to 6:00 p.m., and 24-hr ambient ozone concentrations in the 12 communities during May to September, 1994.

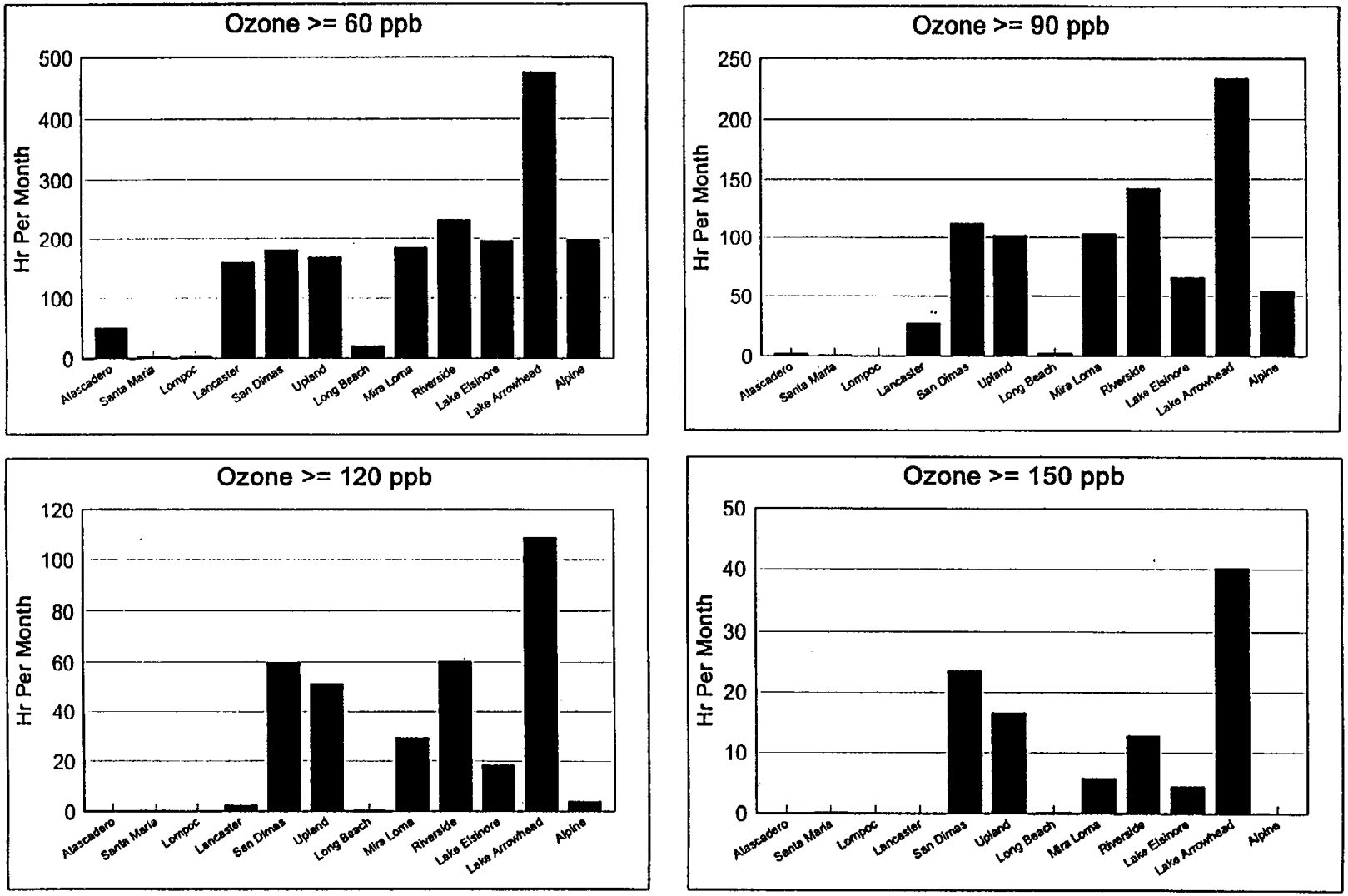


Figure 3-6. Average number of hours per month with ambient ozone concentrations equal to or greater than 60, 90, 120, and 150 ppb in the 12 communities during May to September, 1994.

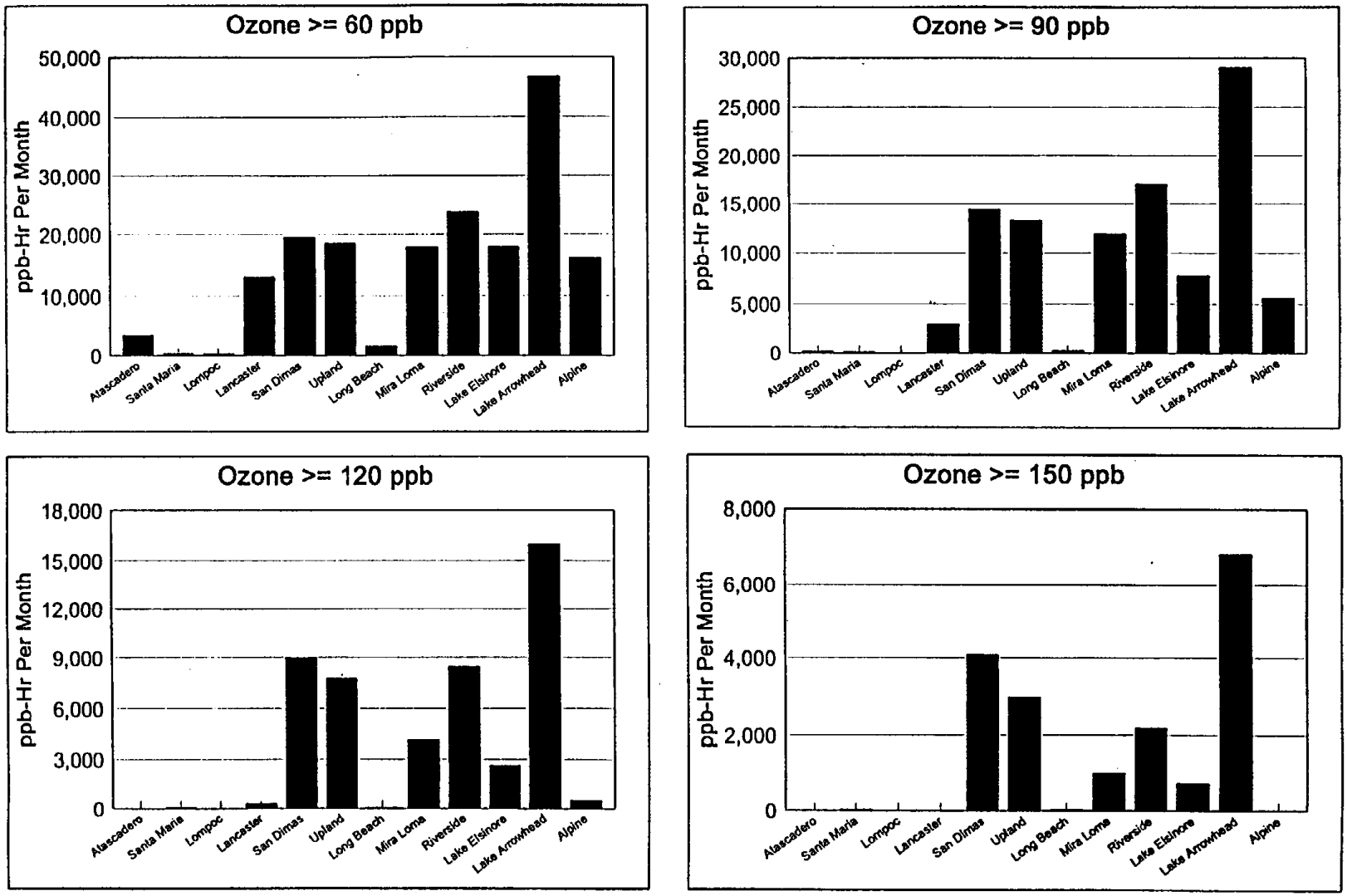


Figure 3-7. Average number of concentration-weighted hours per month with ambient ozone concentrations equal to or greater than 60, 90, 120, and 150 ppb in the 12 communities during May to September, 1994.

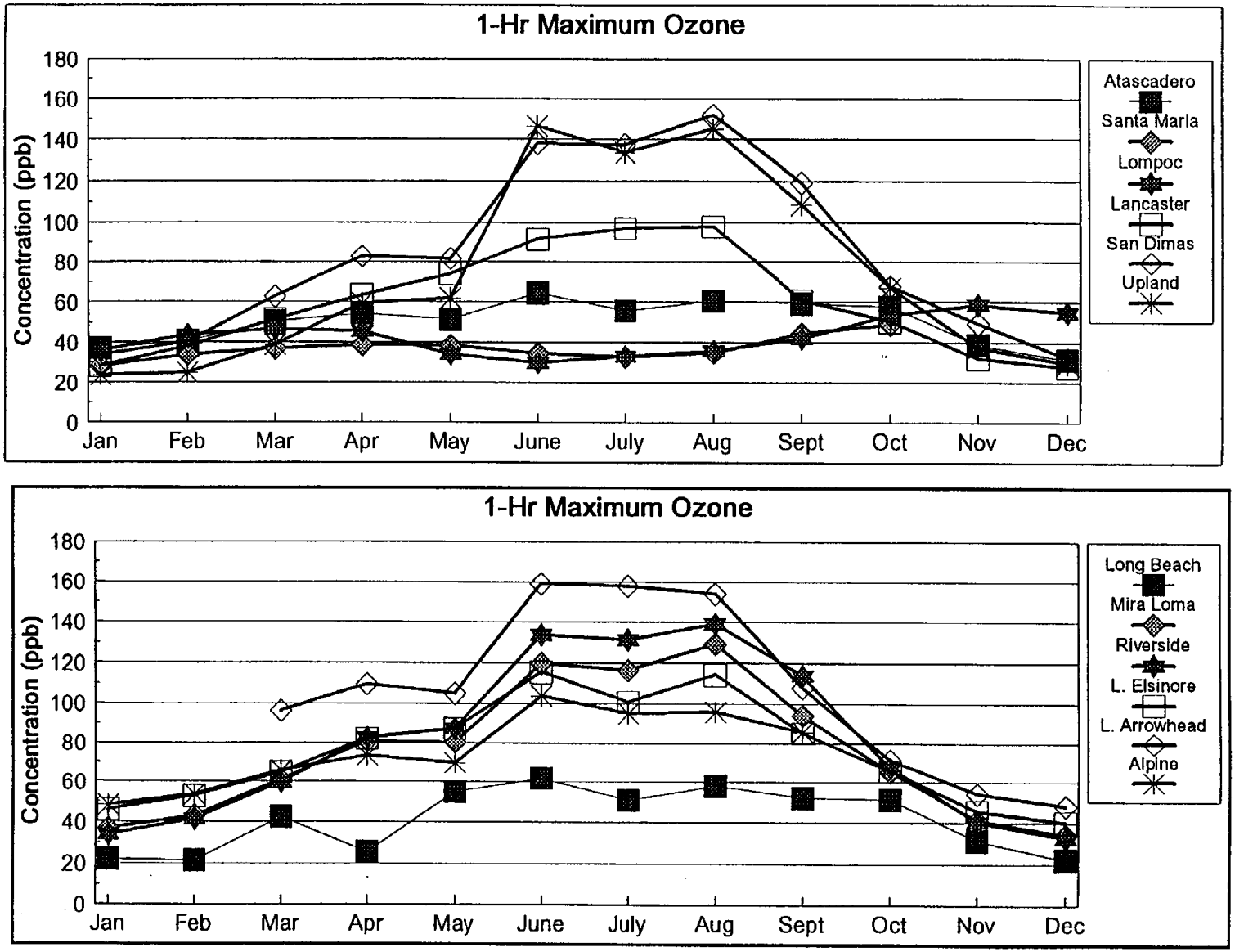


Figure 3-8. Monthly average daily 1-hr maximum ambient ozone concentration by community in 1994.

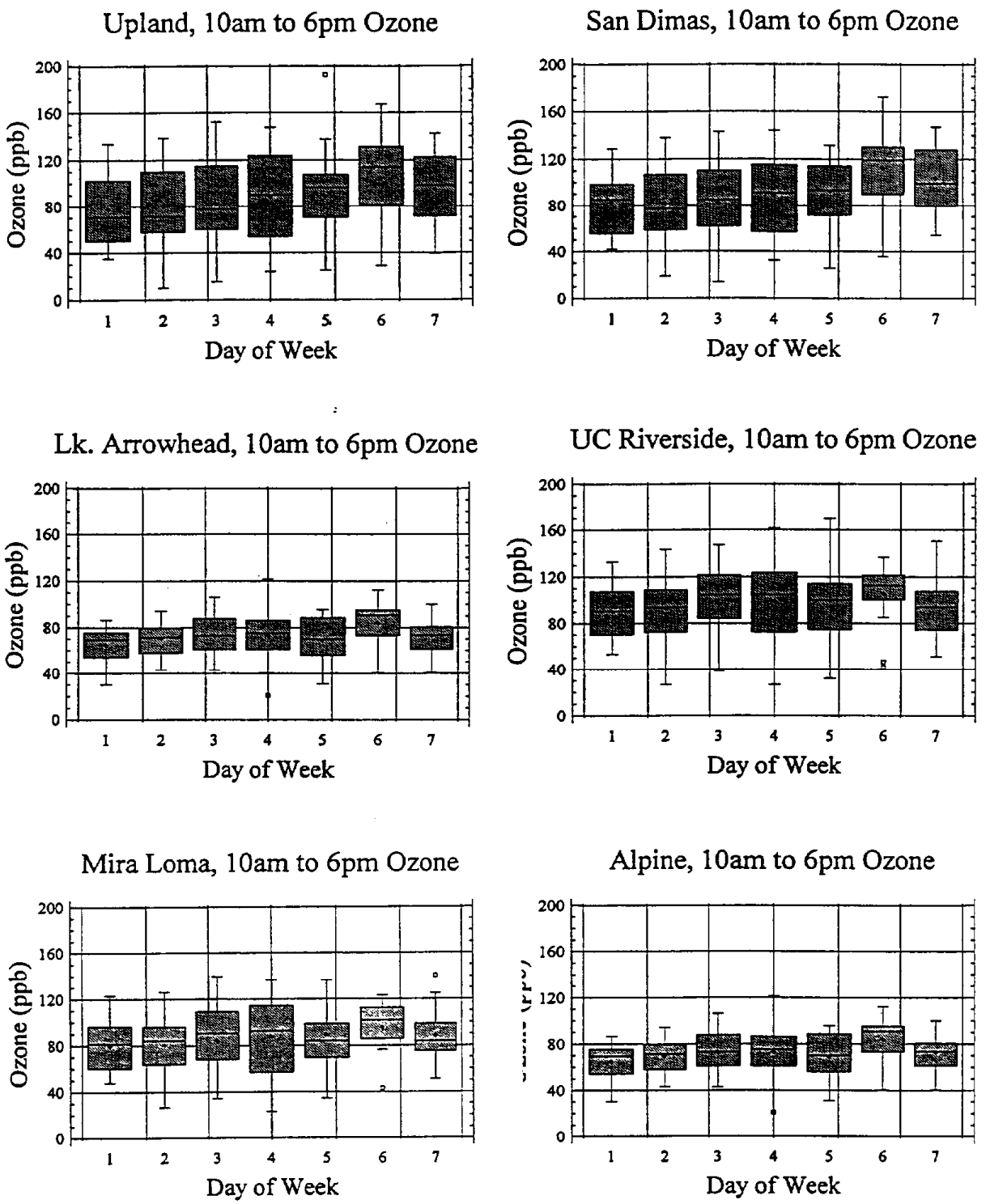
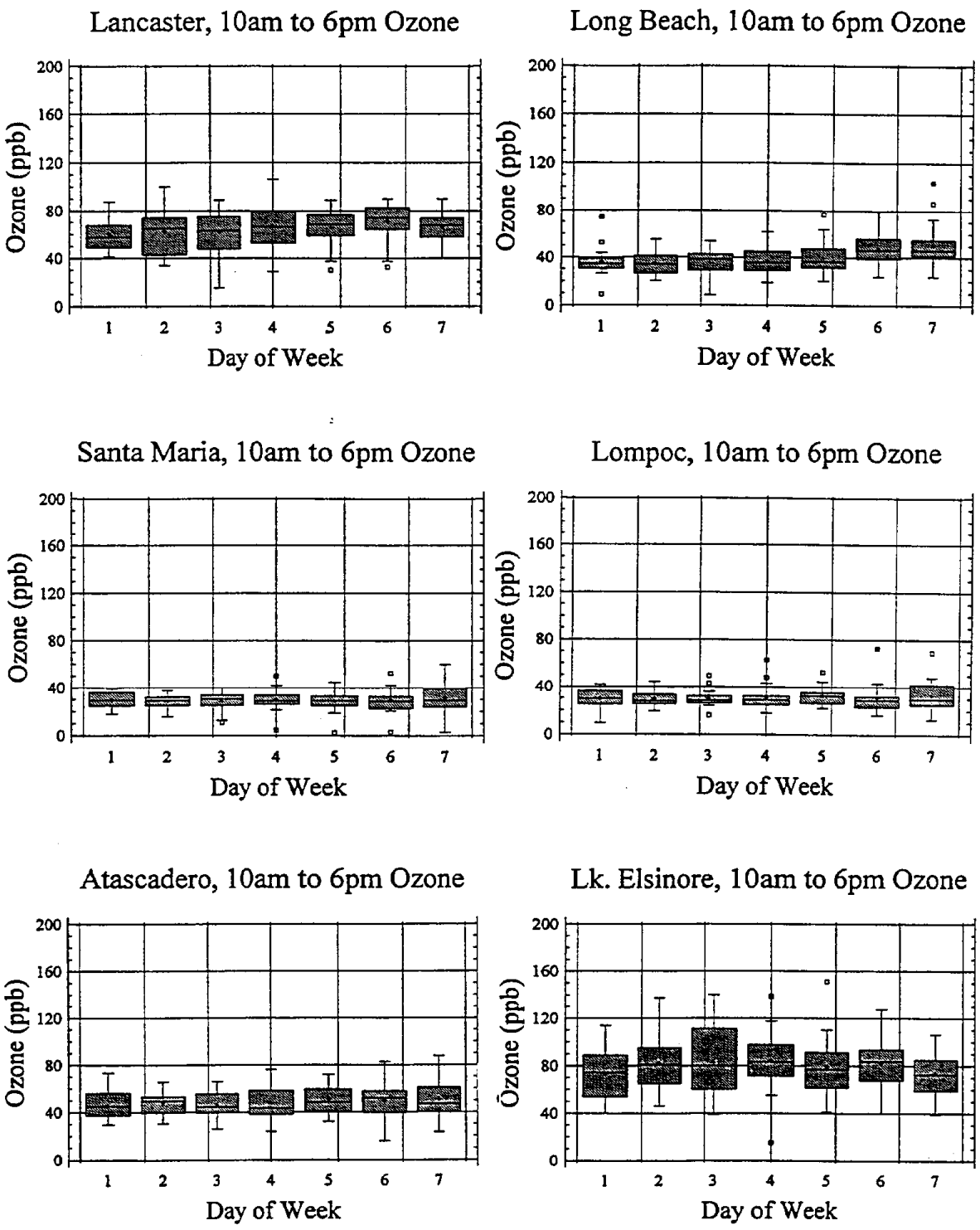


Figure 3-9. Day-of-week variations in 10:00 a.m. to 6:00 p.m. ambient ozone concentrations in six communities.



1=Monday; 2=Tuesday; 3=Wednesday; 4=Thursday; 5=Friday; 6=Saturday; 7=Sunday

Figure 3-10. Day-of-week variations in 10:00 a.m. to 6:00 p.m. ambient ozone concentrations in six communities.

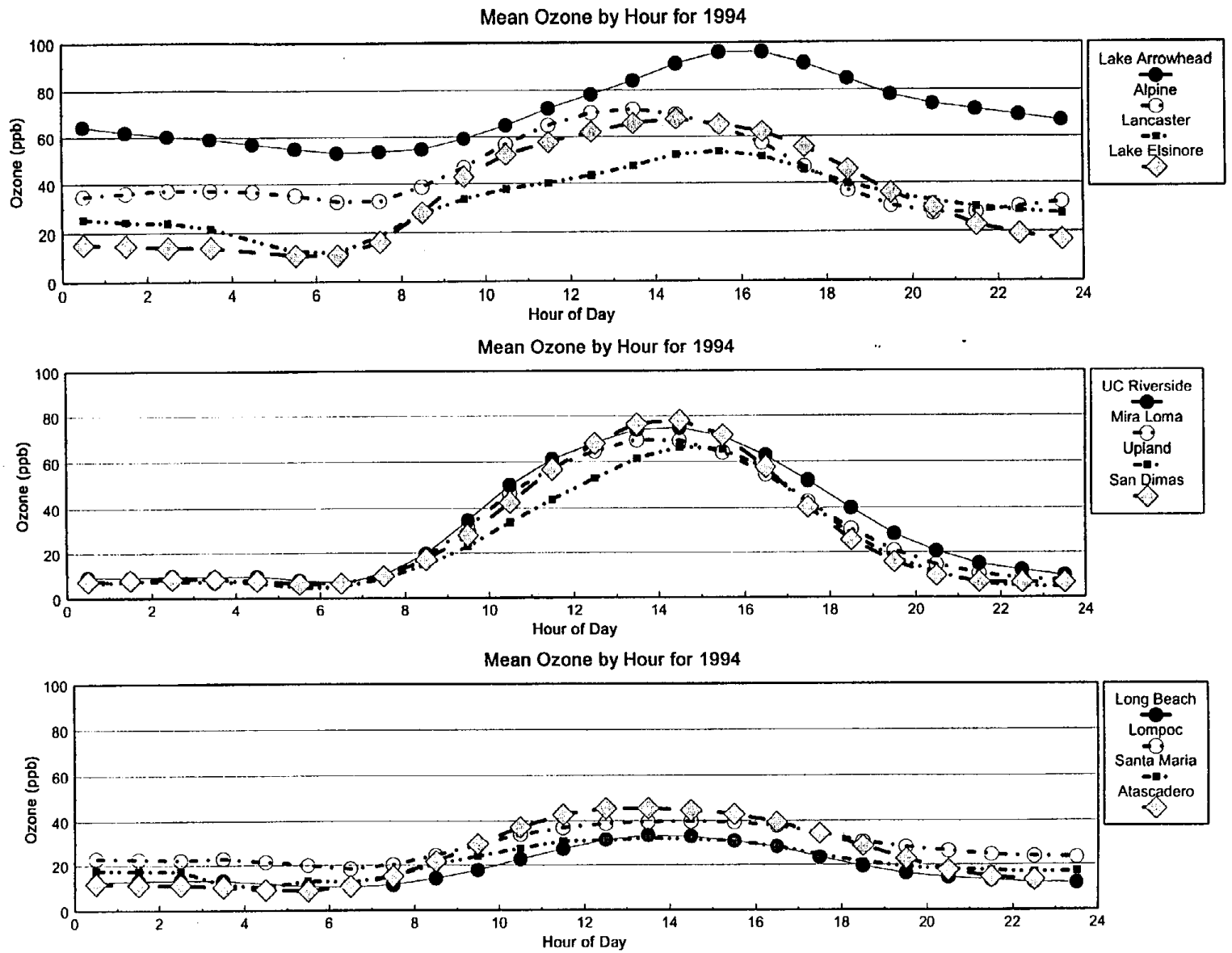


Figure 3-11. Mean ozone concentration by hour of day for the 12 study communities in 1994.

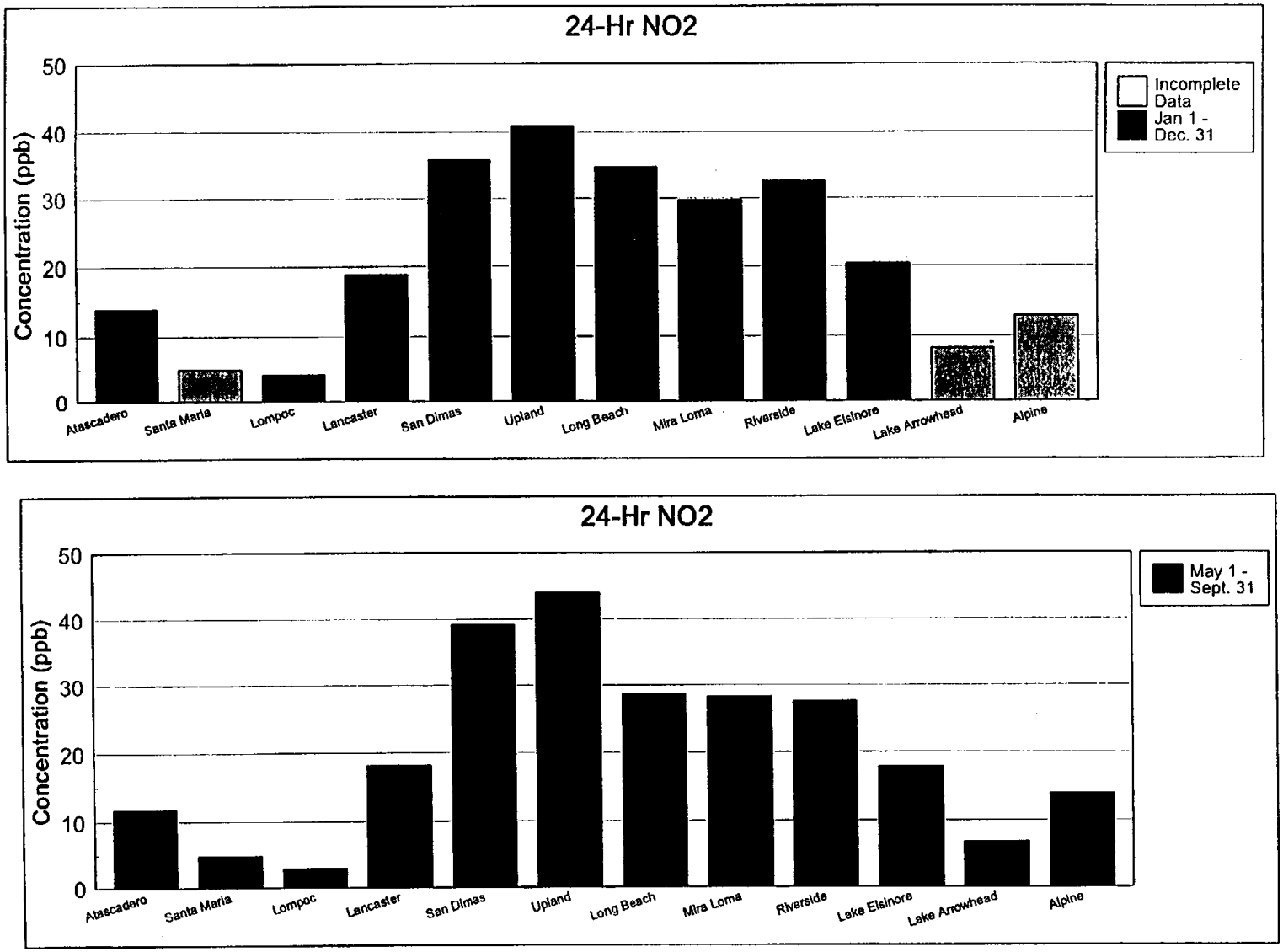
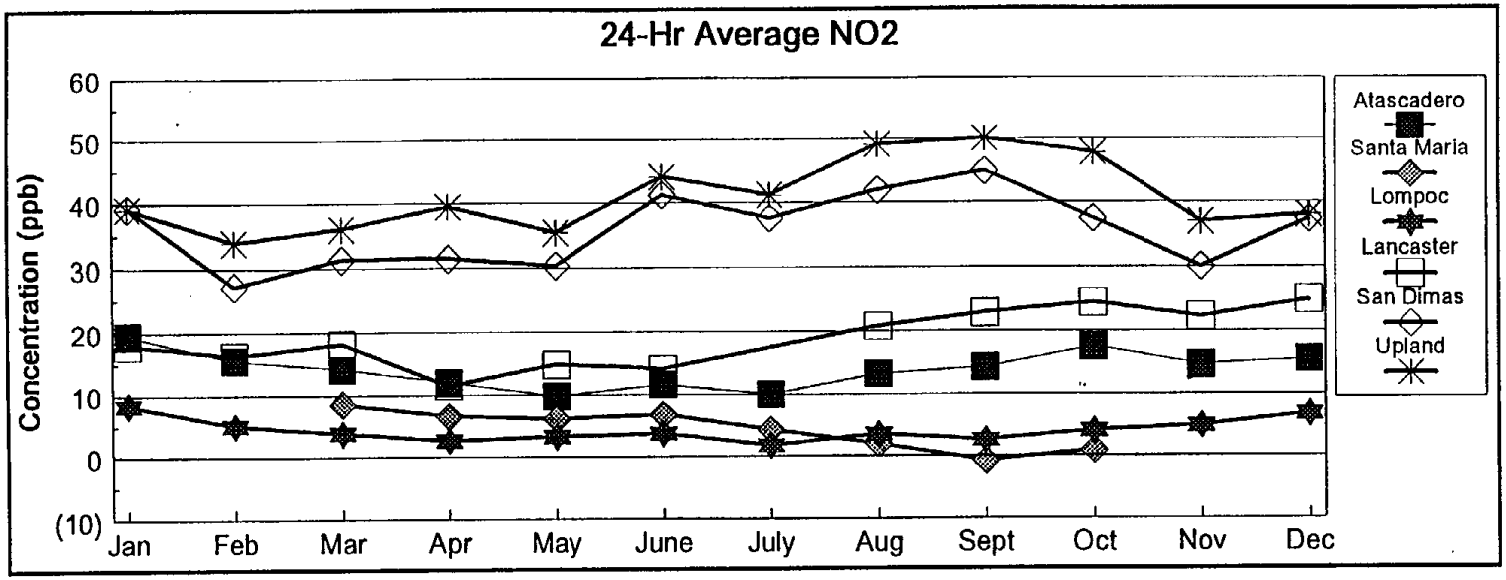


Figure 3-12. Annual average and May to September 24-hr average NO_2 ambient concentrations in the 12 communities in 1994.



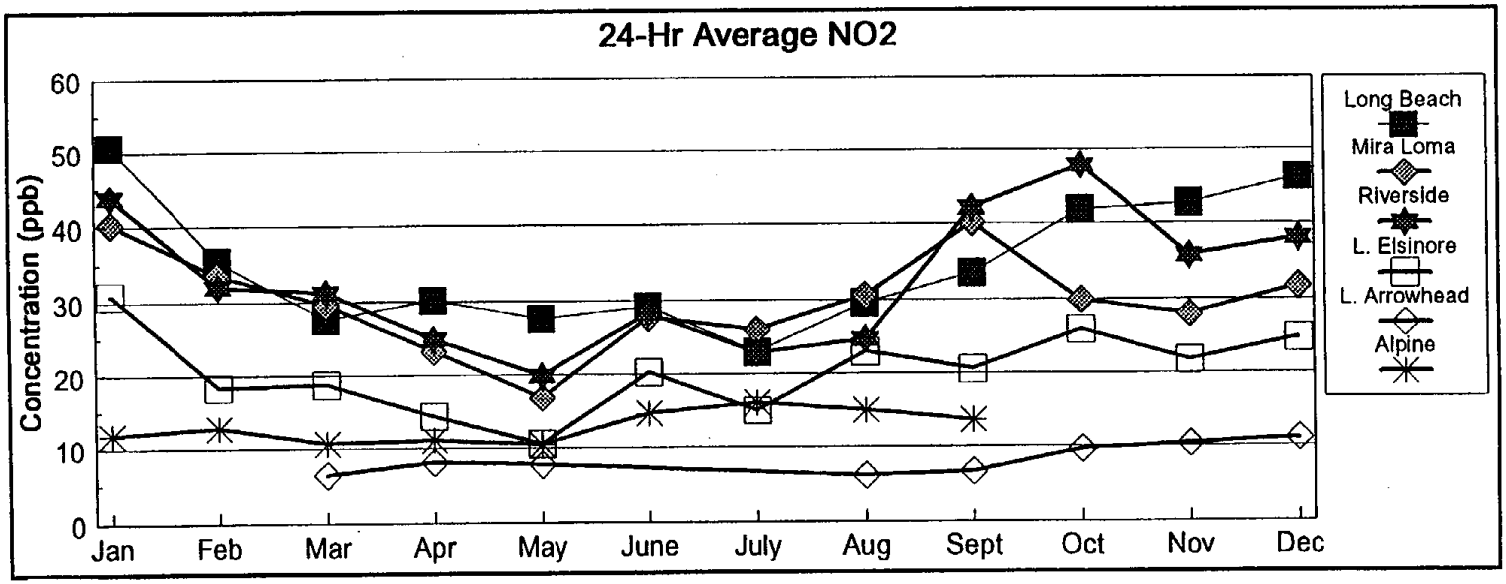


Figure 3-13. Monthly variations in 24-hr average NO_2 ambient concentrations in the 12 communities in 1994.

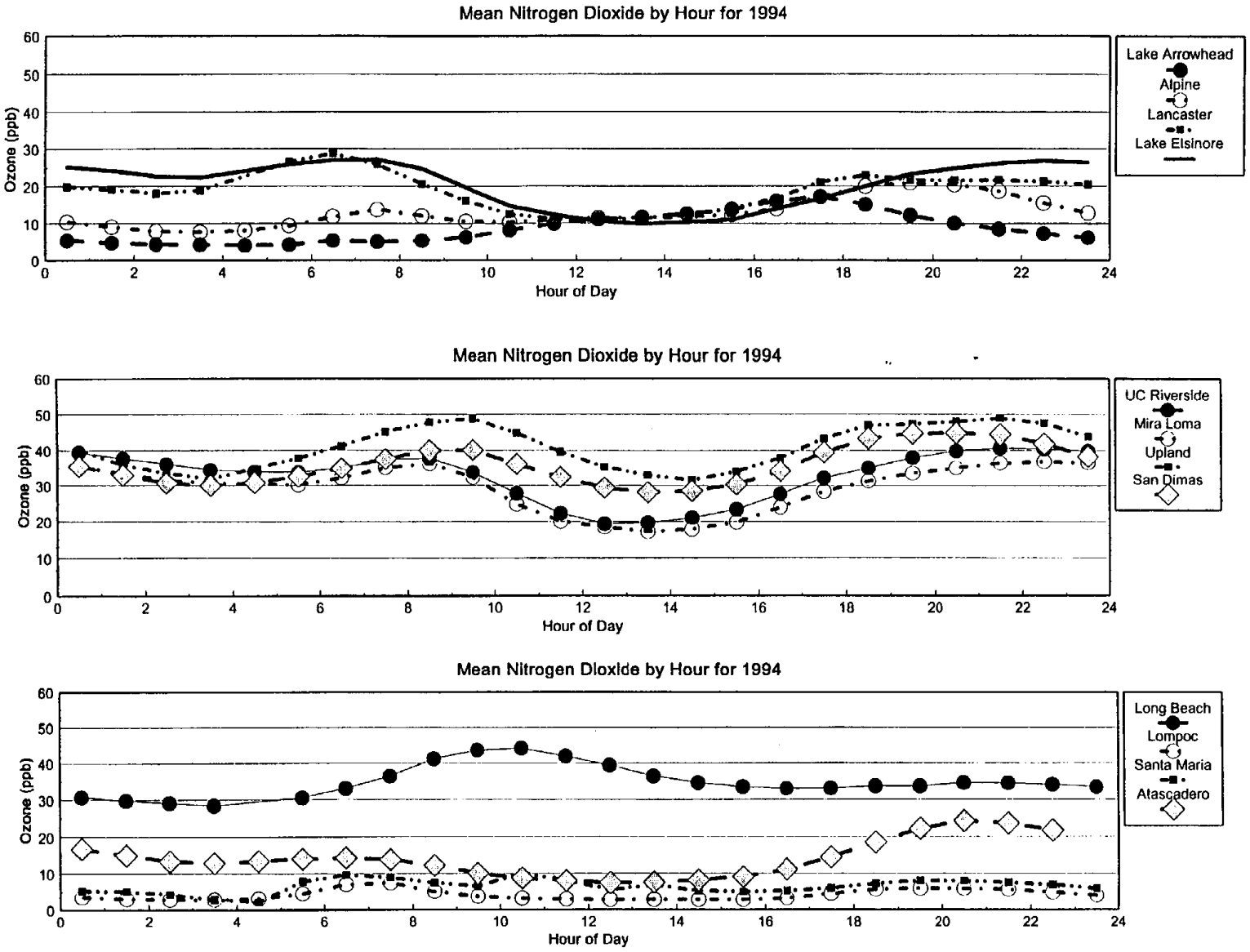


Figure 3-14. Mean nitrogen dioxide concentration by hour of day for the 12 study communities in 1994.

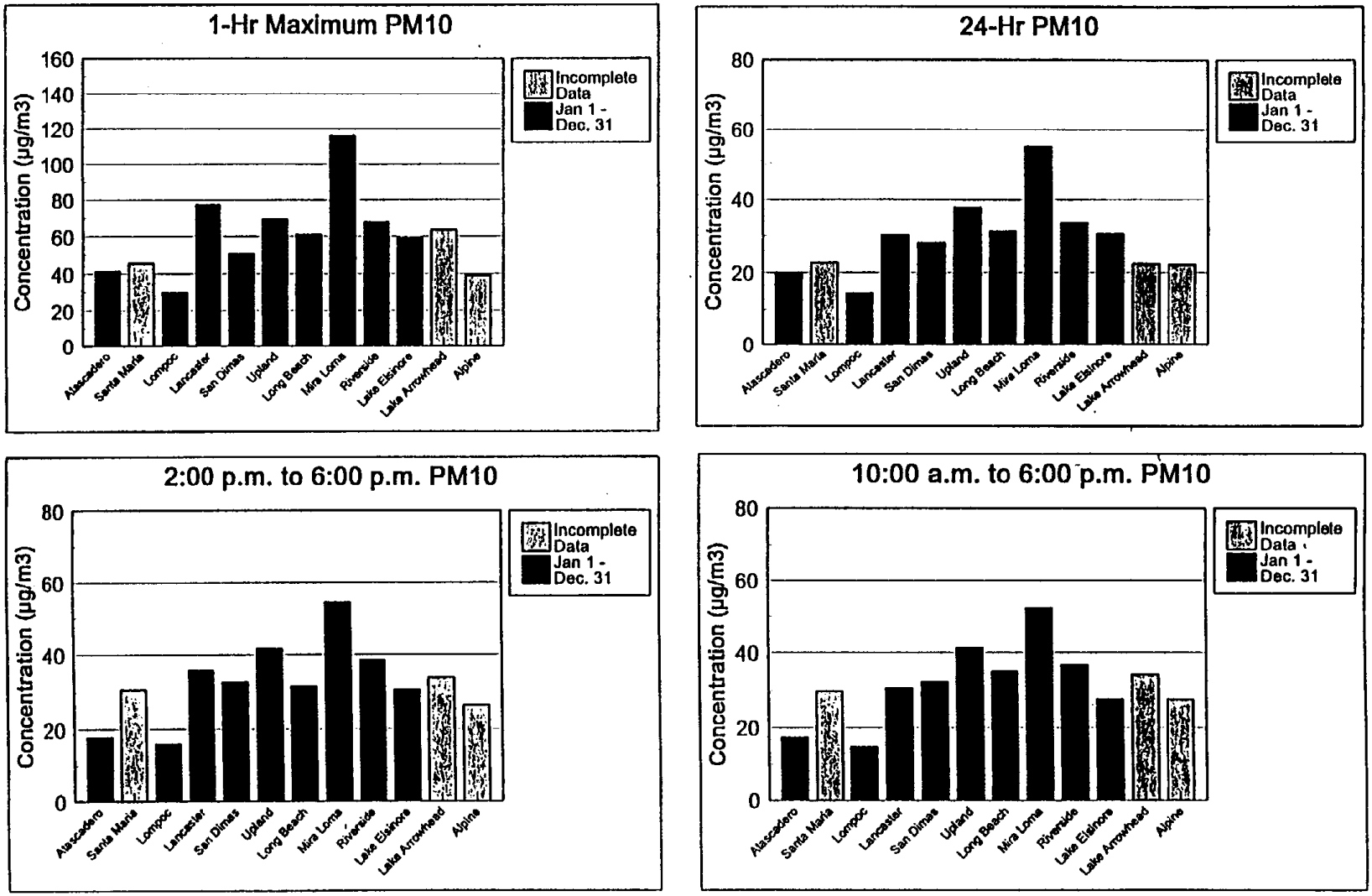
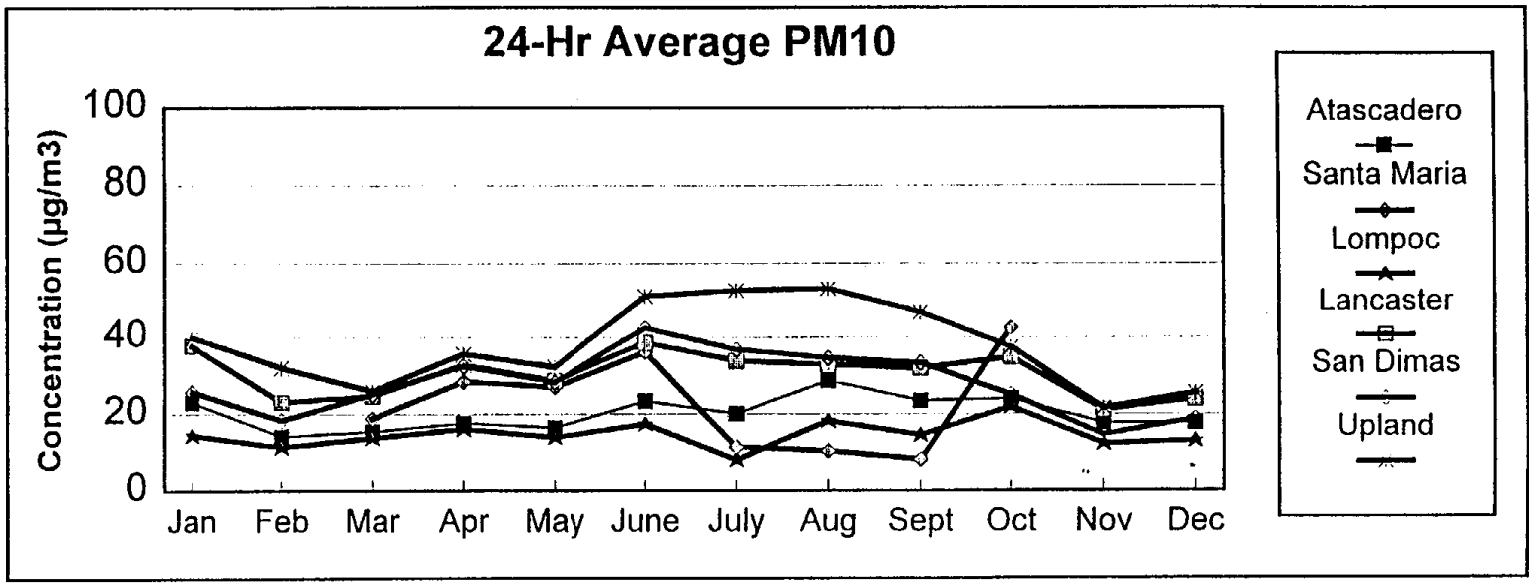


Figure 3-15. Annual average daily 1-hr maximum, 24-hr, 2:00 p.m. to 6:00 p.m., and 10:00 a.m. to 6:00 p.m. ambient PM_{10} concentrations in the 12 communities in 1994.



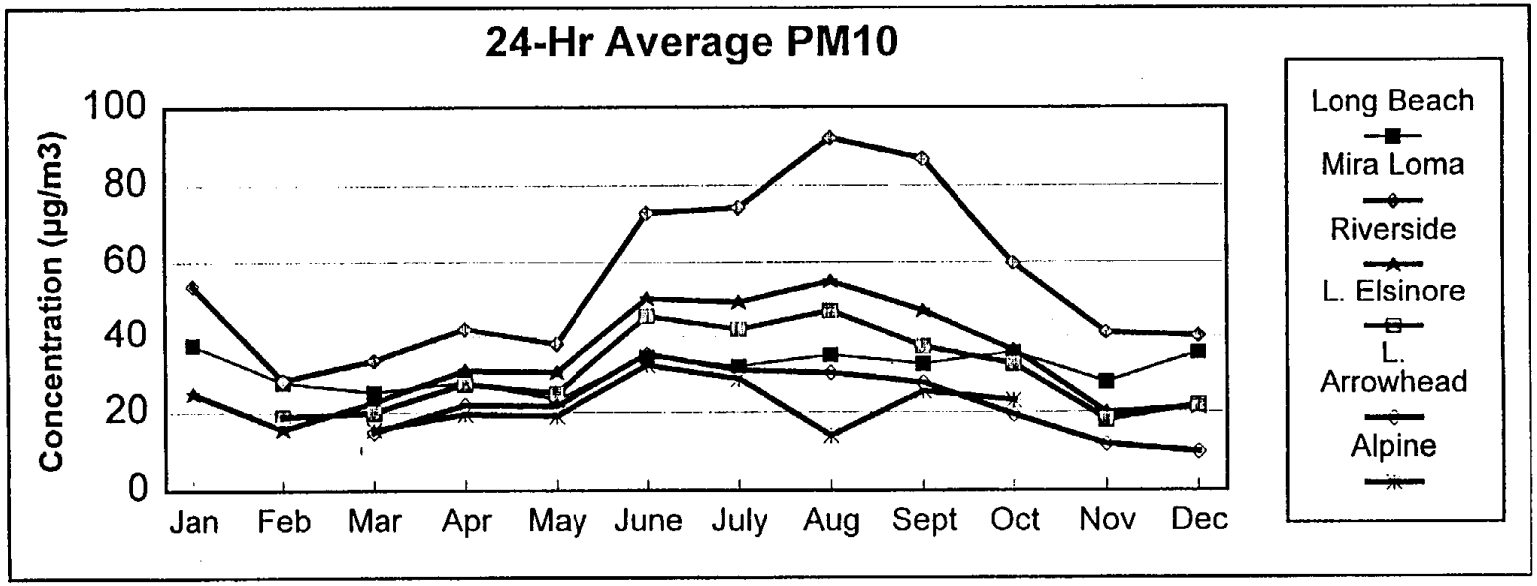


Figure 3-16. Monthly variations in 24-hr average PM_{10} ambient concentrations in the 12 communities in 1994.

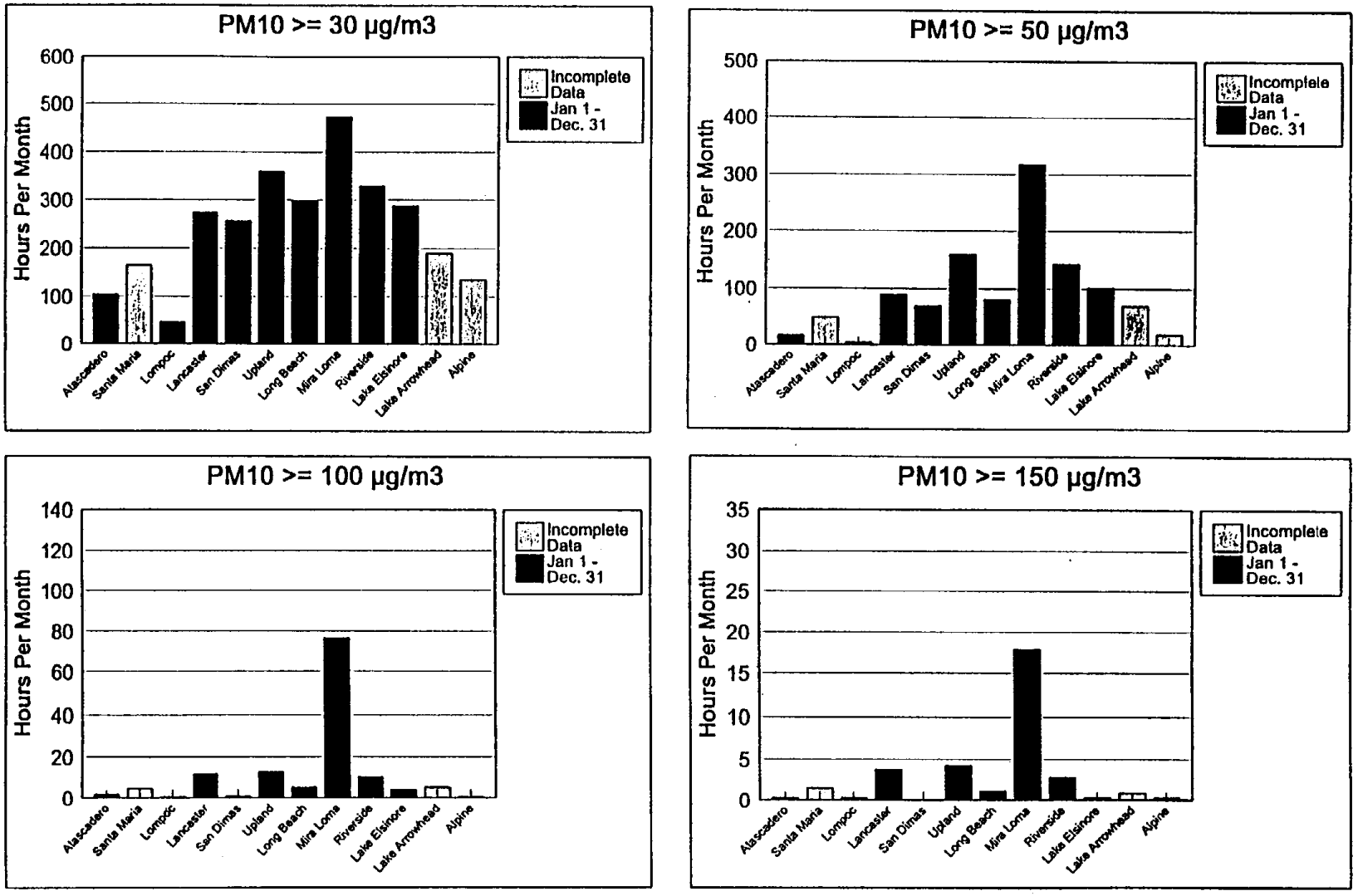


Figure 3-17. Annual average number of hours per month with ambient ozone concentrations equal to or greater than 30, 50, 100, and 150 $\mu g/m^3$ in the 12 communities in 1994.

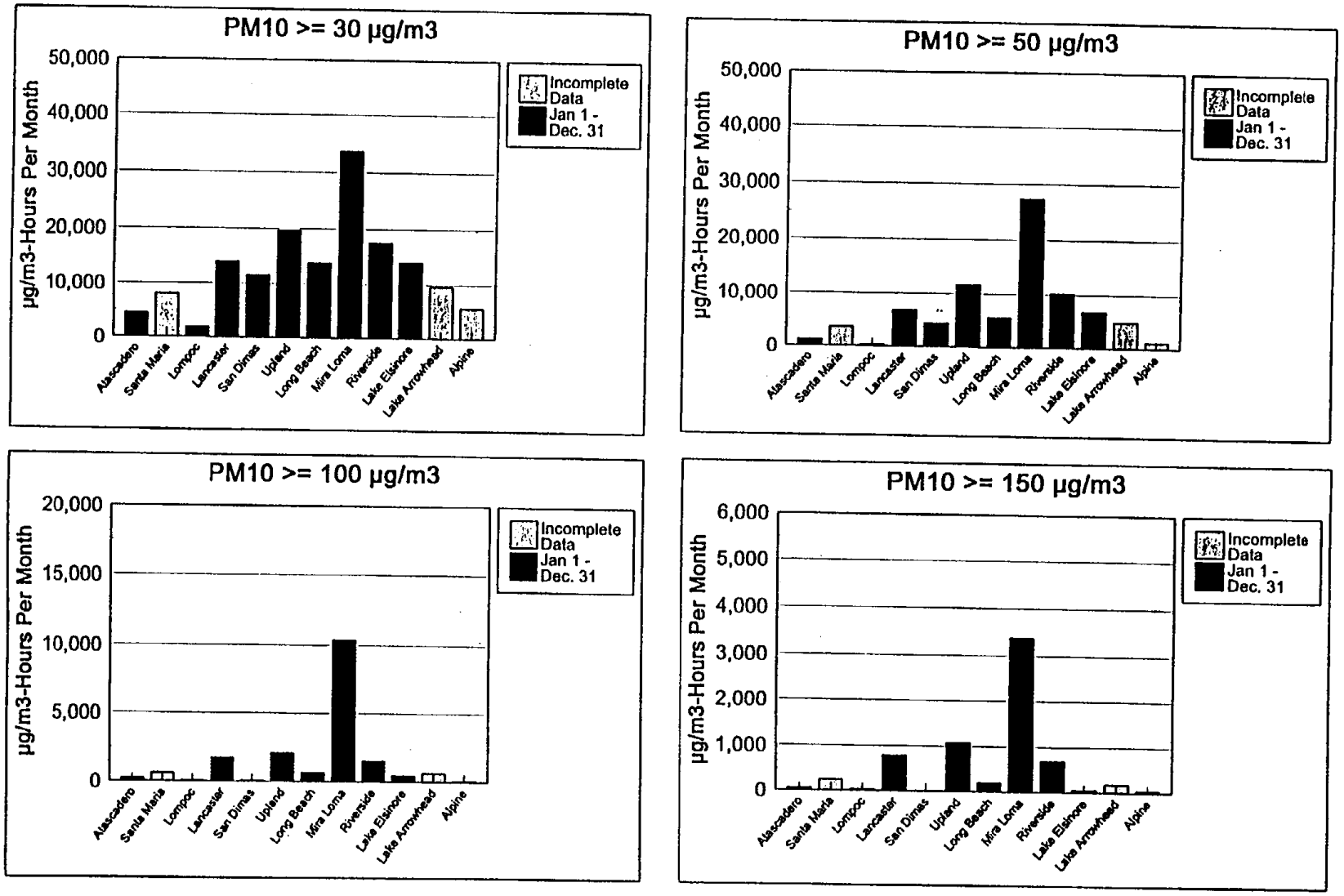


Figure 3-18. Annual average number of concentration-weighted hours per month with ambient PM_{10} concentrations equal to or greater than 30, 50, 100, and 150 $\mu g/m^3$ in the 12 communities in 1994.

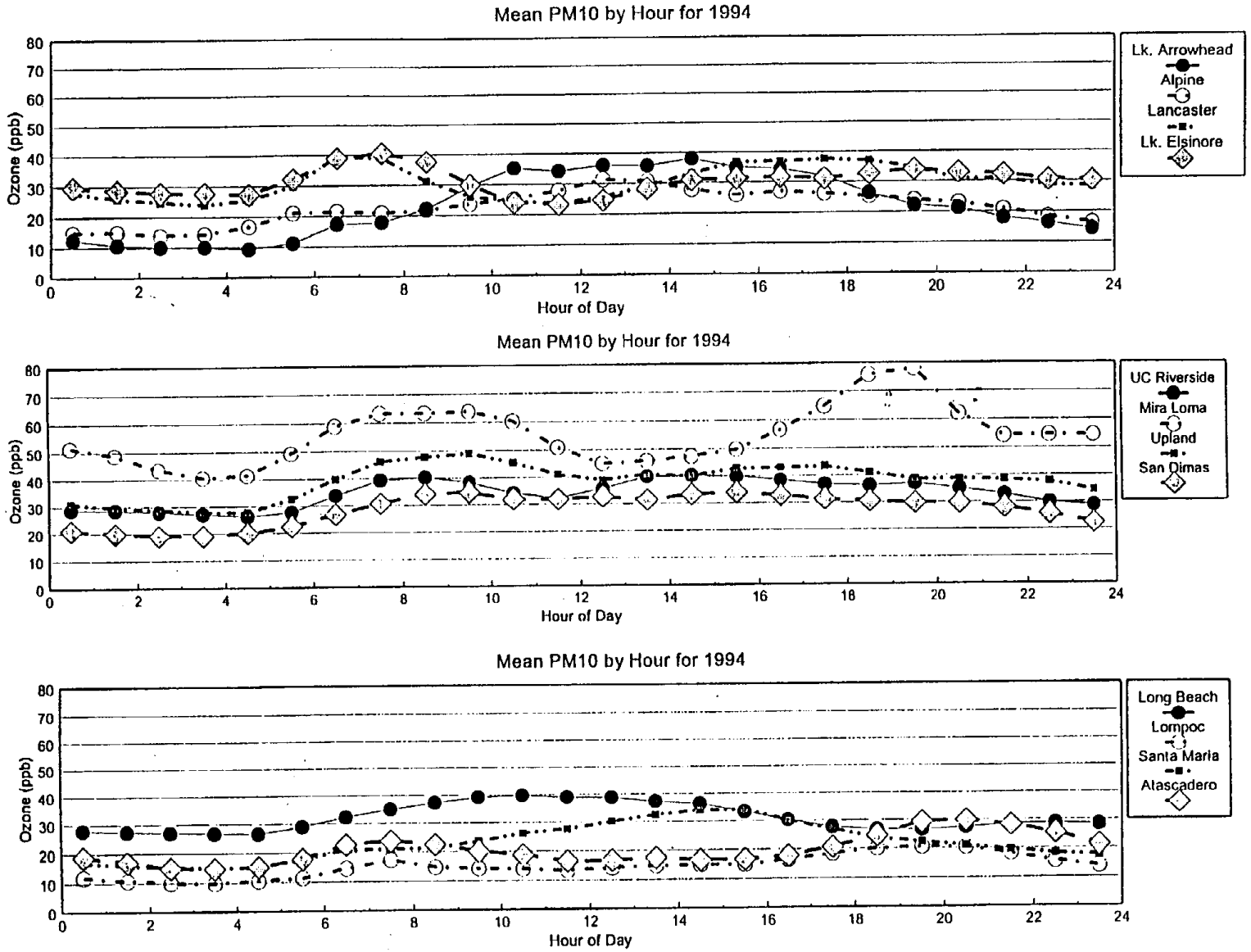


Figure 3-19. Mean PM_{10} concentration by hour of day for the 12 study communities in 1994.

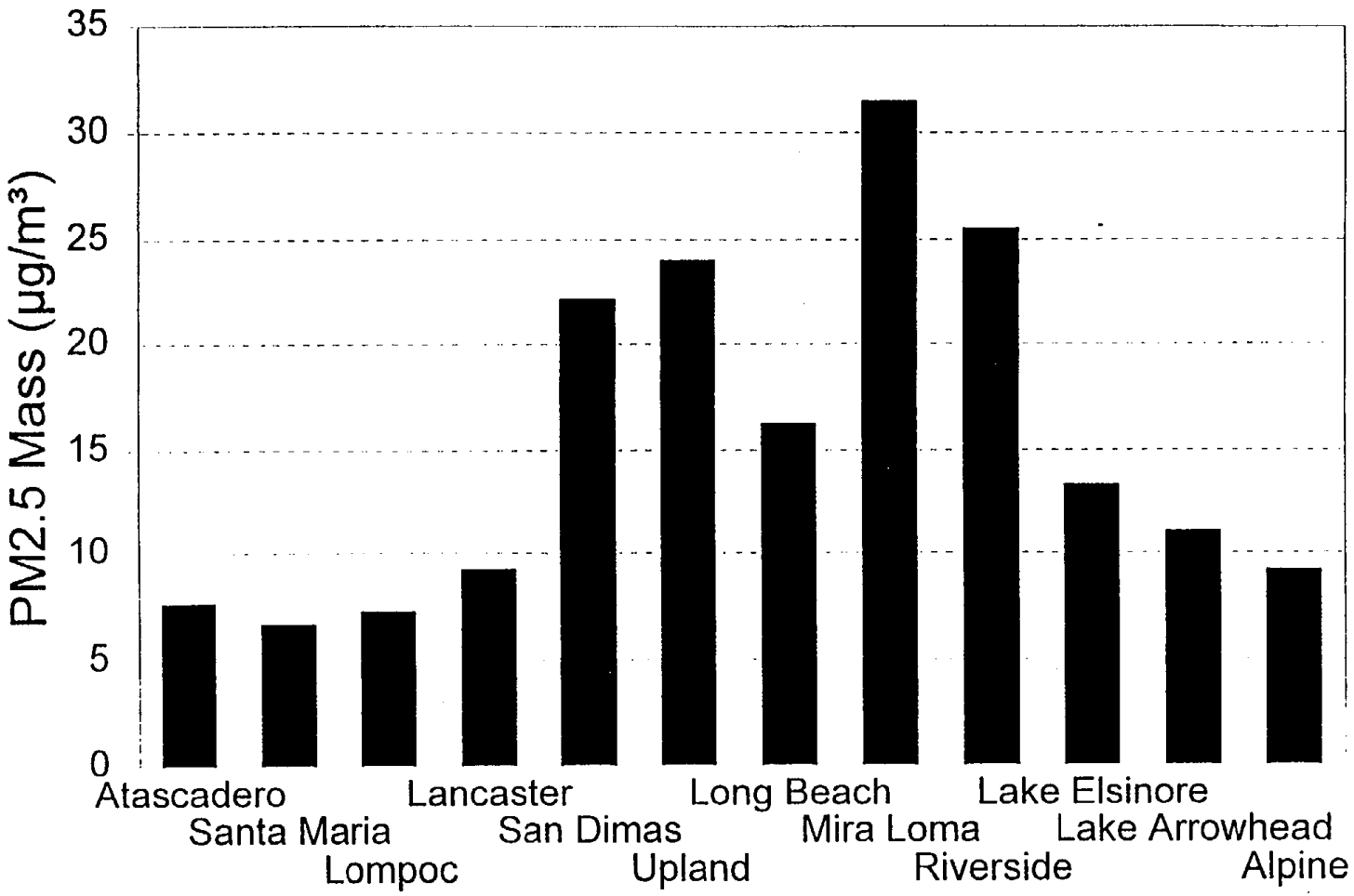


Figure 3-20. Average ambient $PM_{2.5}$ concentrations in the 12 communities in 1994.

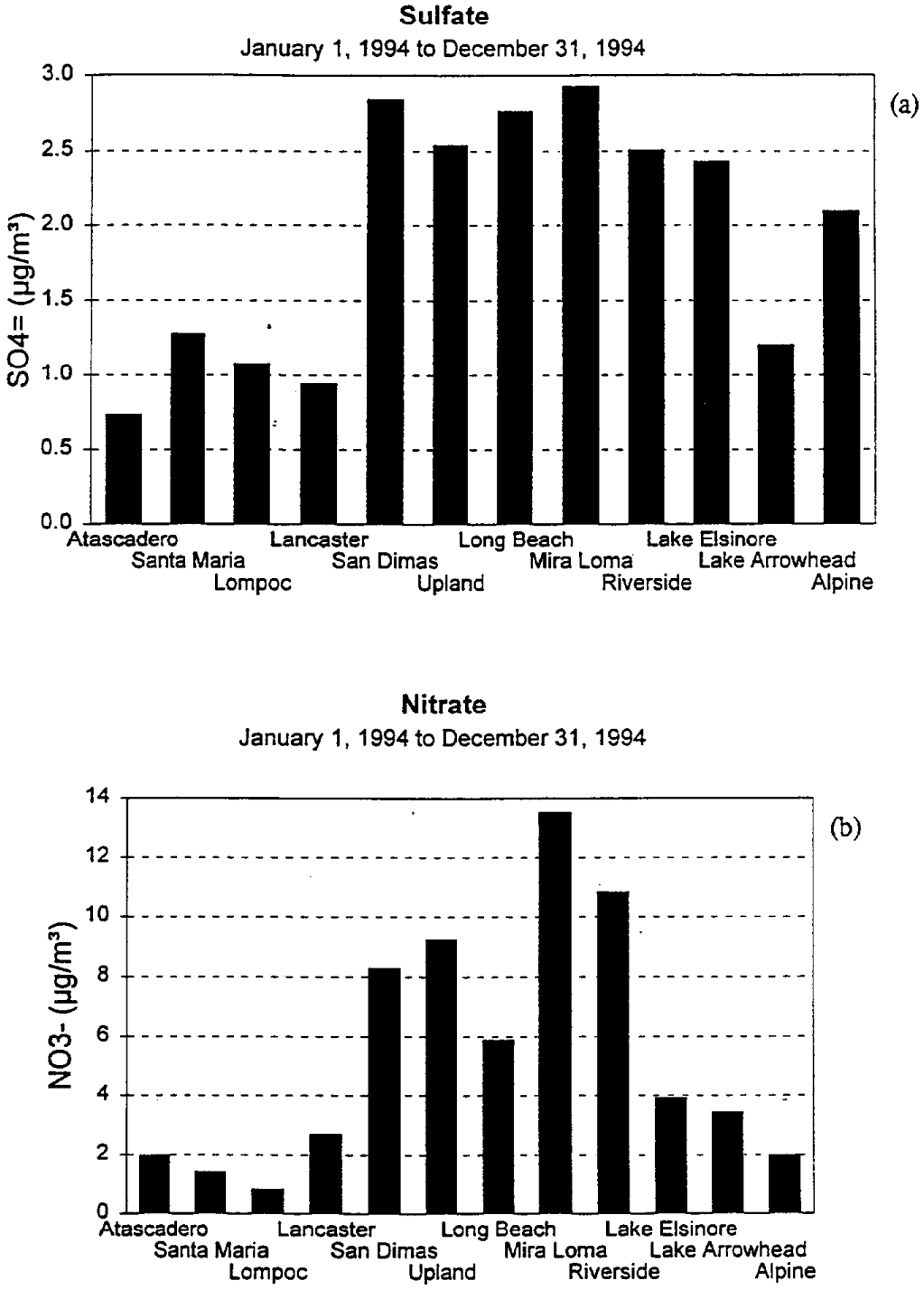


Figure 3-21. Average ambient (a) $PM_{2.5}$ sulfate and (b) $PM_{2.5}$ nitrate concentrations in the 12 communities in 1994

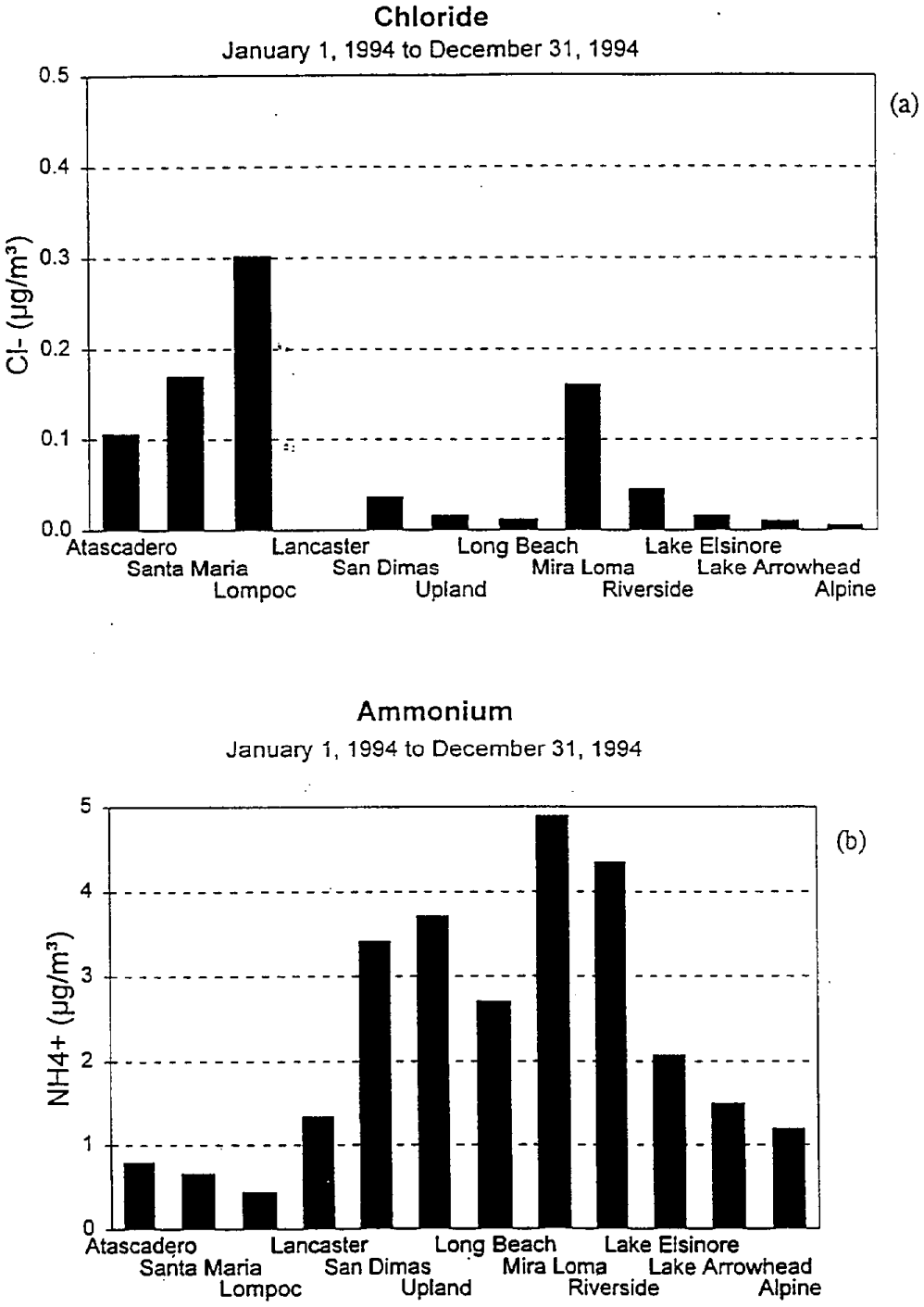


Figure 3-22. Average ambient of (a) $PM_{2.5}$ chloride and (b) $PM_{2.5}$ ammonium concentrations in the 12 communities in 1994.

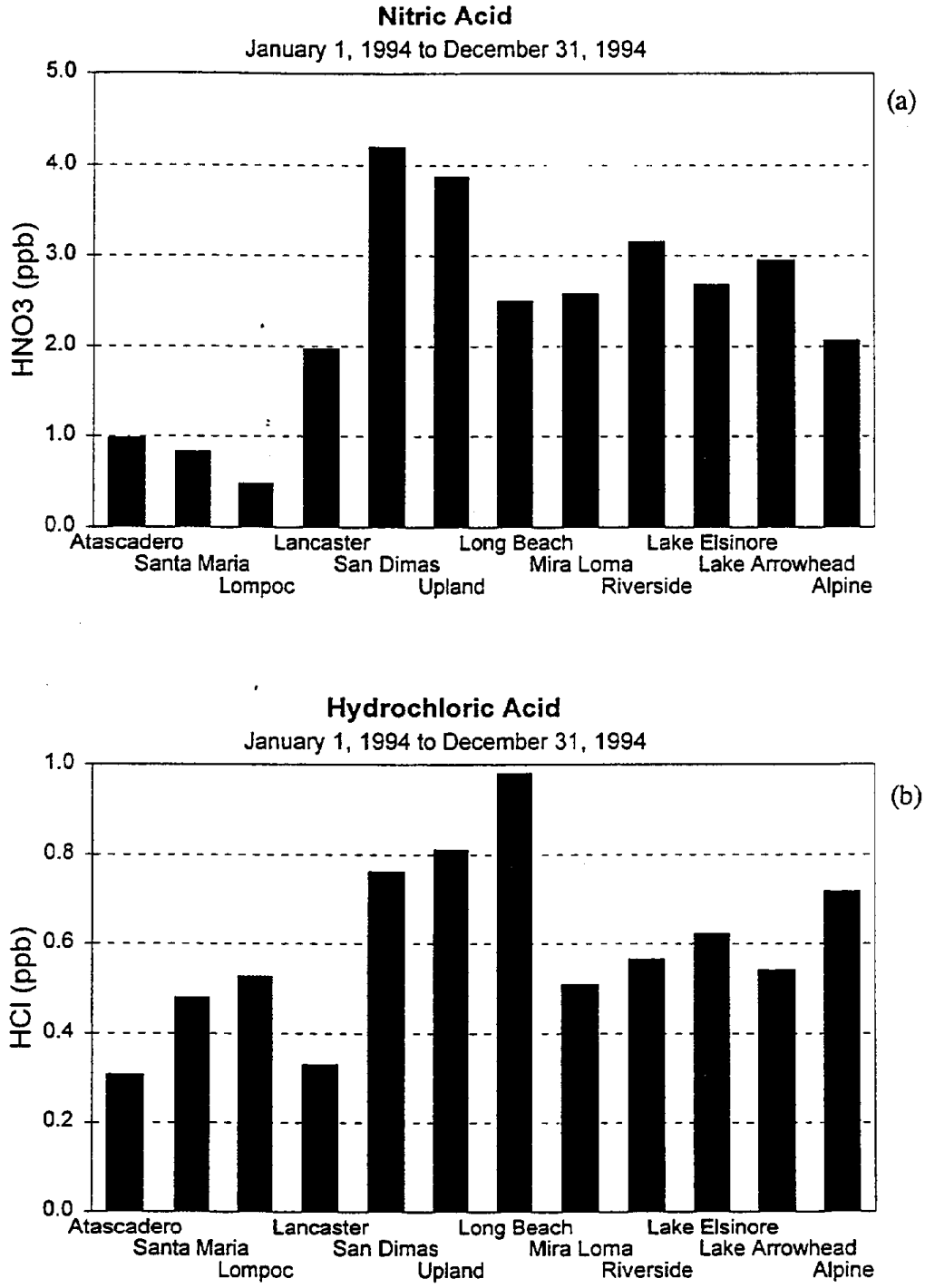


Figure 3-23. Average ambient (a) nitric acid and (b) hydrochloric acid concentrations in the 12 communities in 1994.

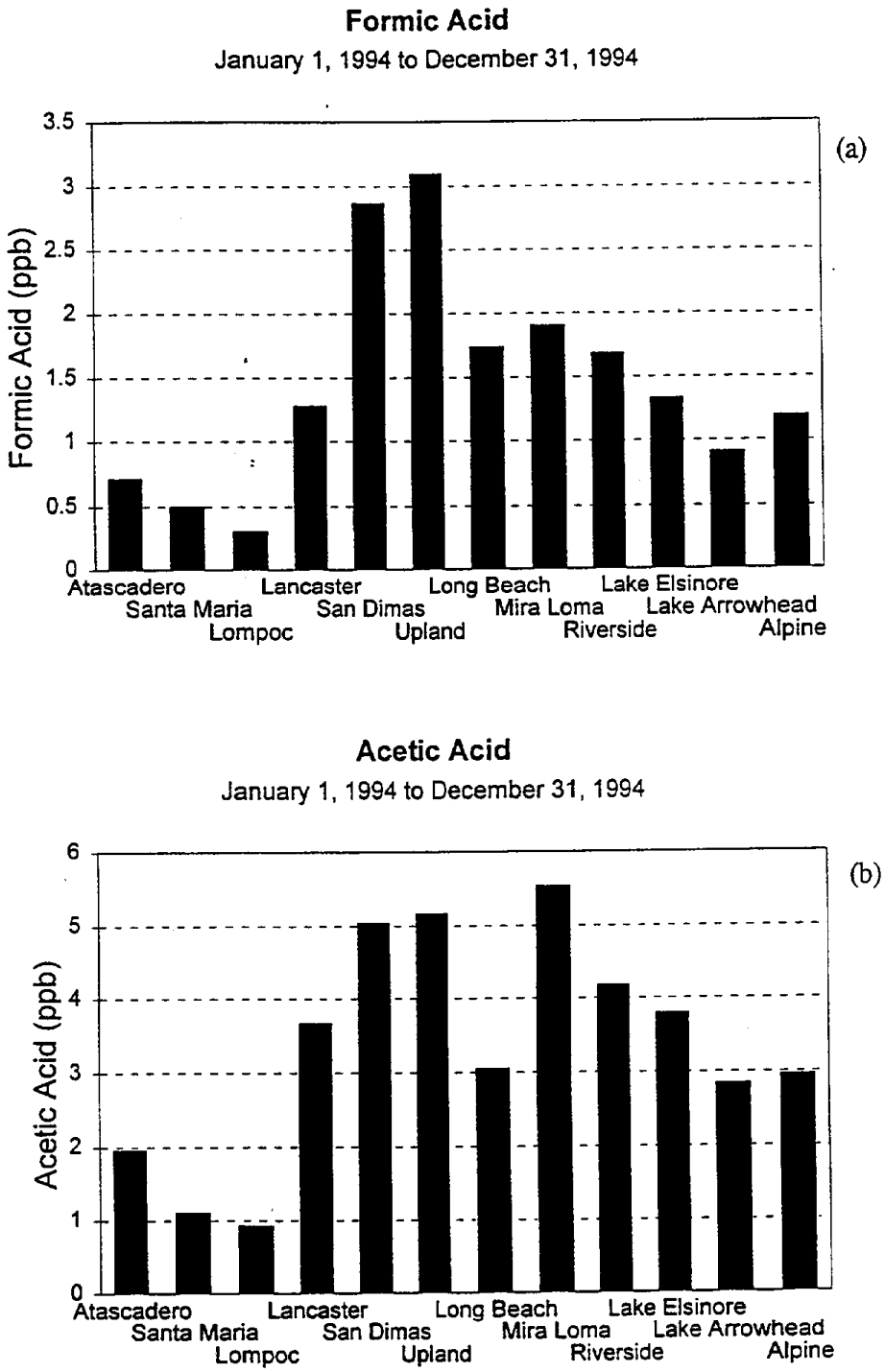


Figure 3-24. Average ambient (a) formic acid and (b) acetic acid concentrations in the 12 communities in 1994.

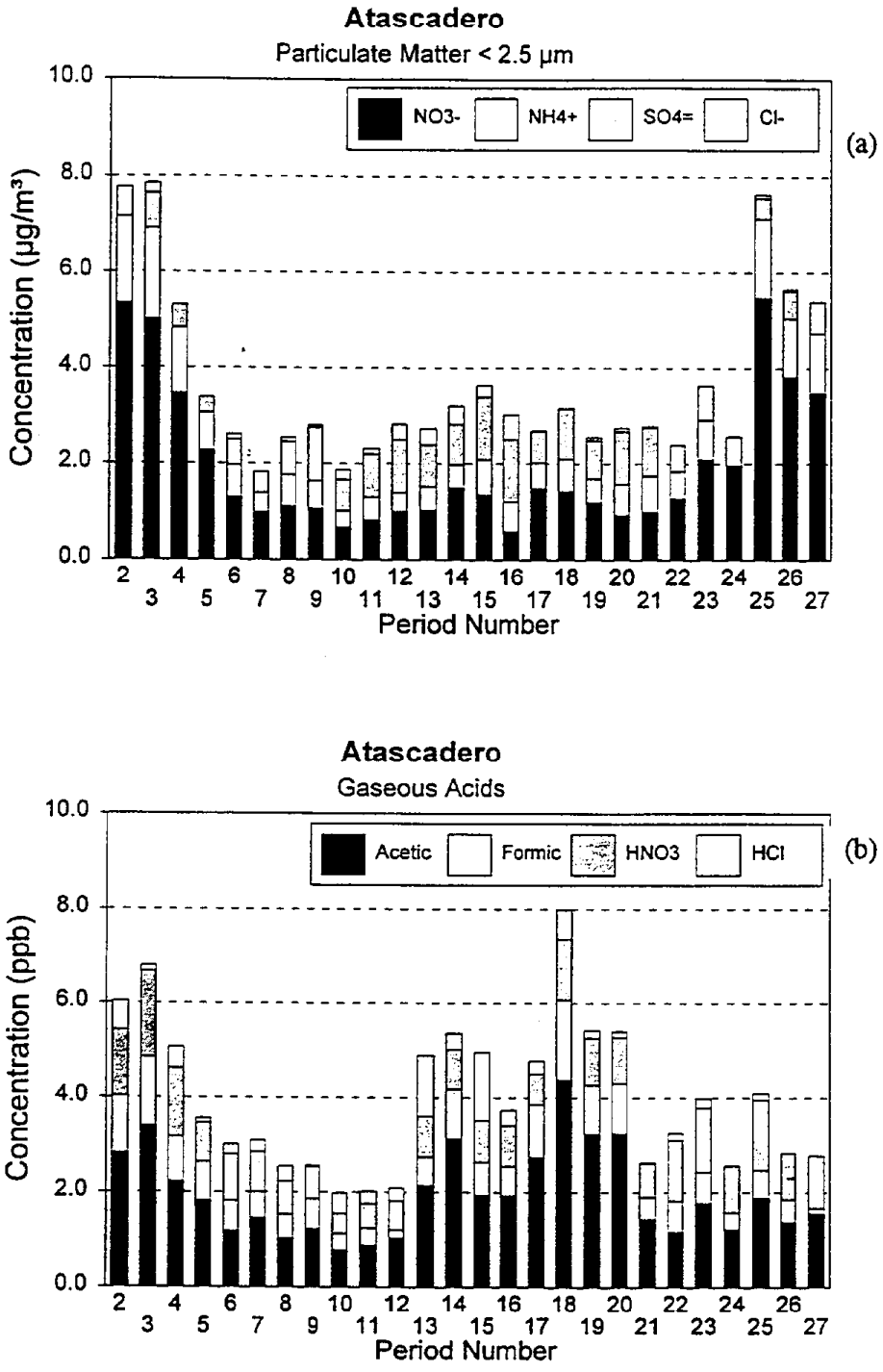


Figure 3-25. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in Atascadero.

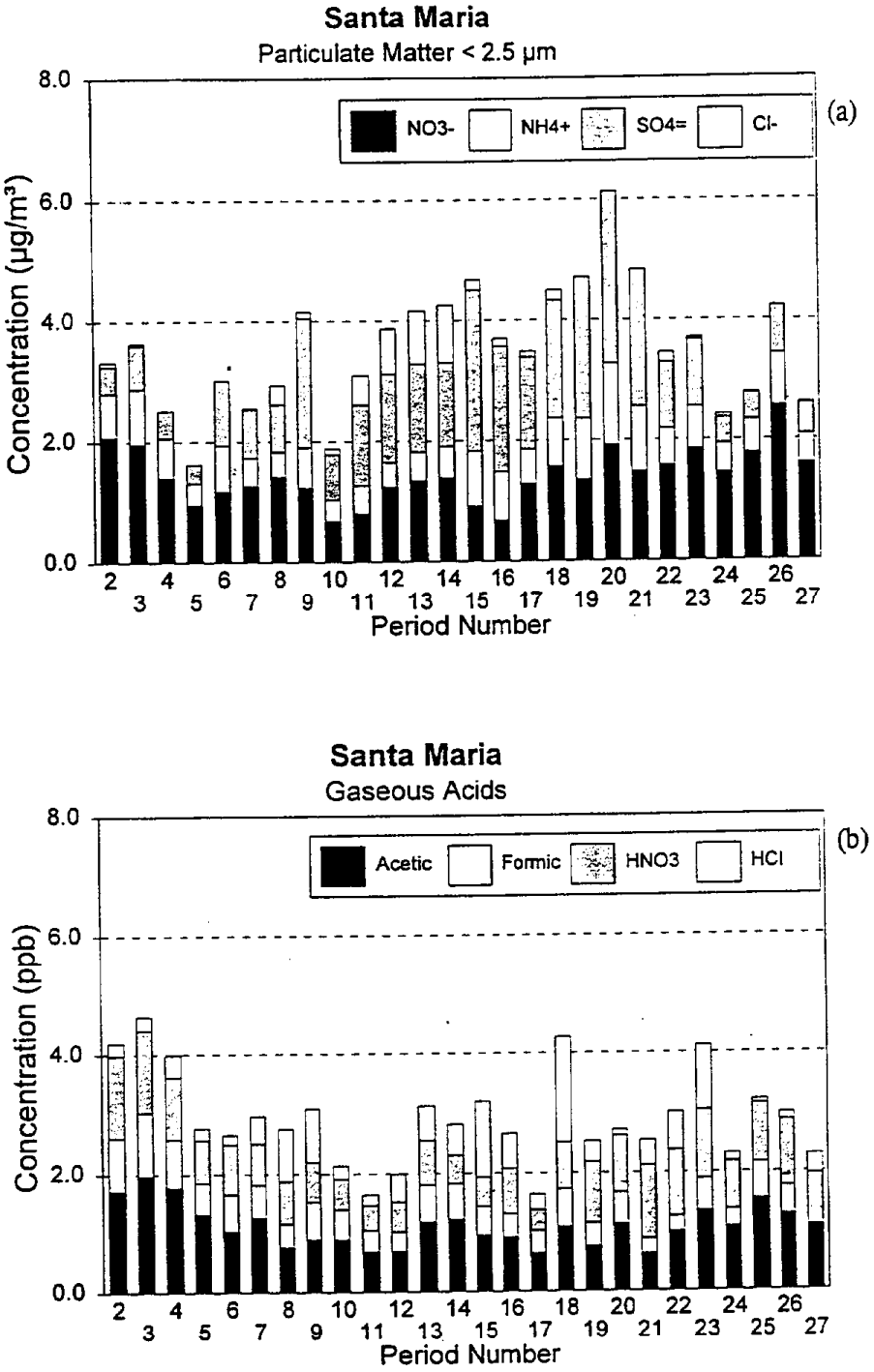


Figure 3-26. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in Santa Maria.

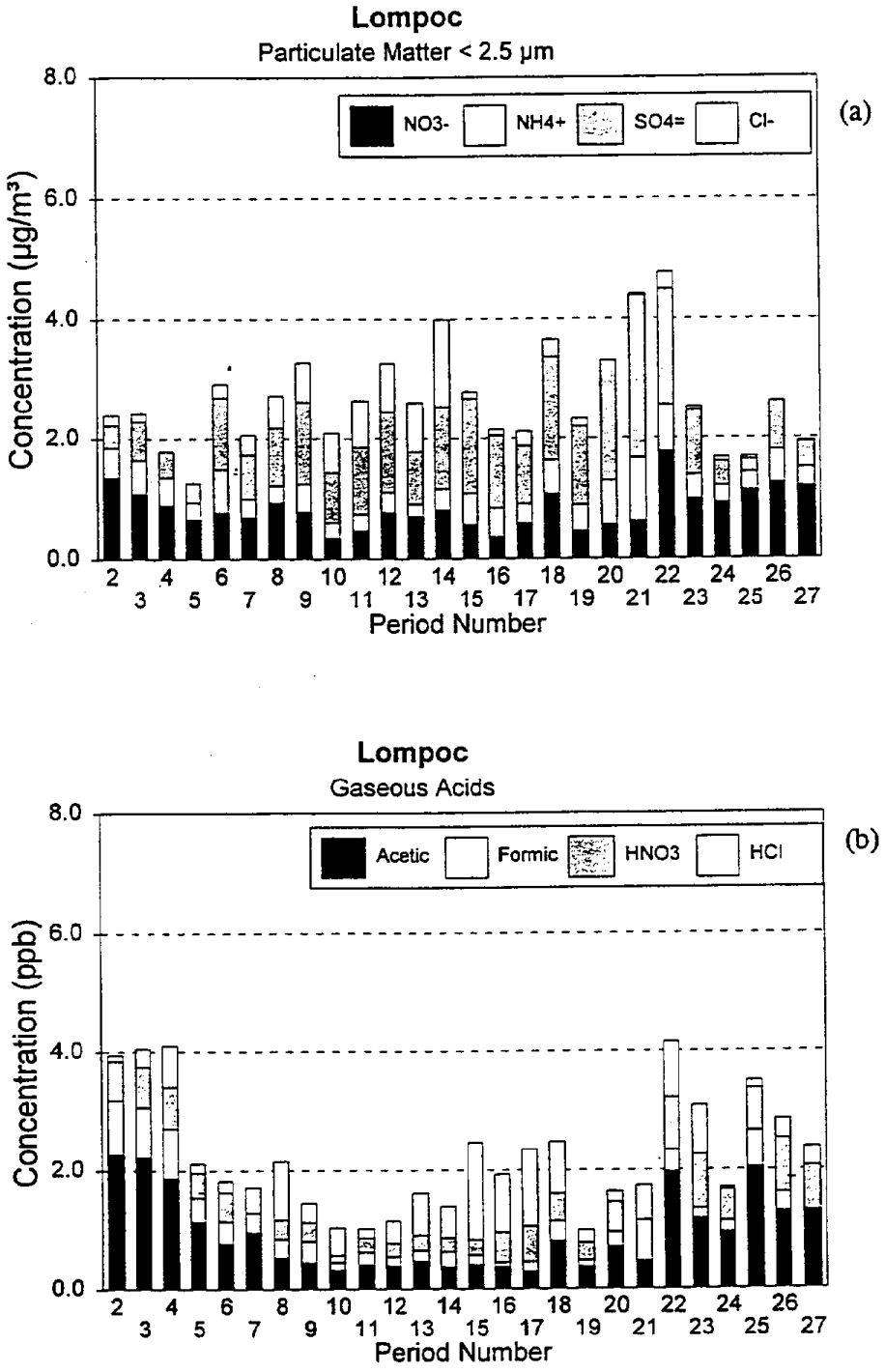


Figure 3-27. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in Lompoc.

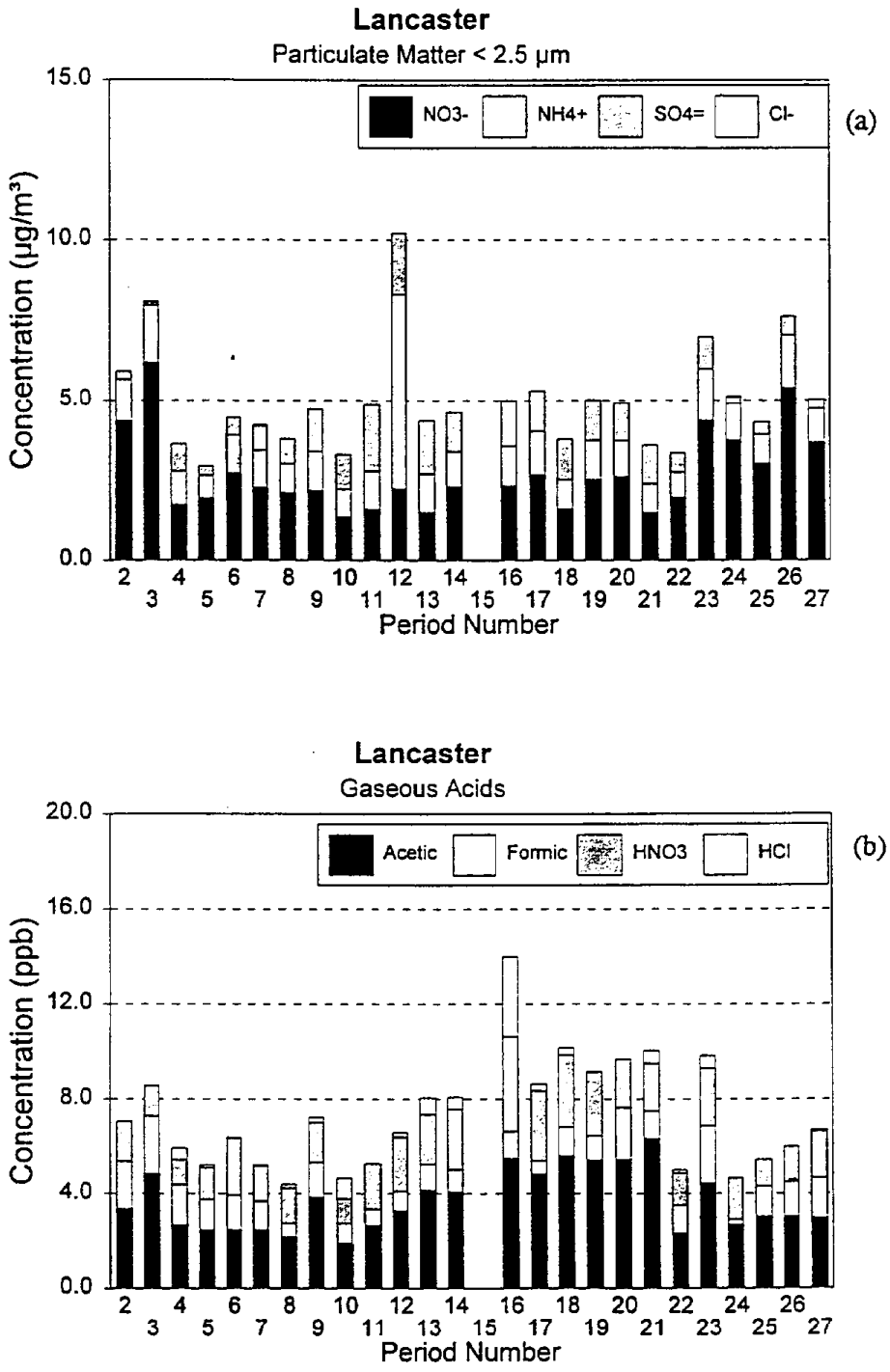


Figure 3-28. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in Lancaster.

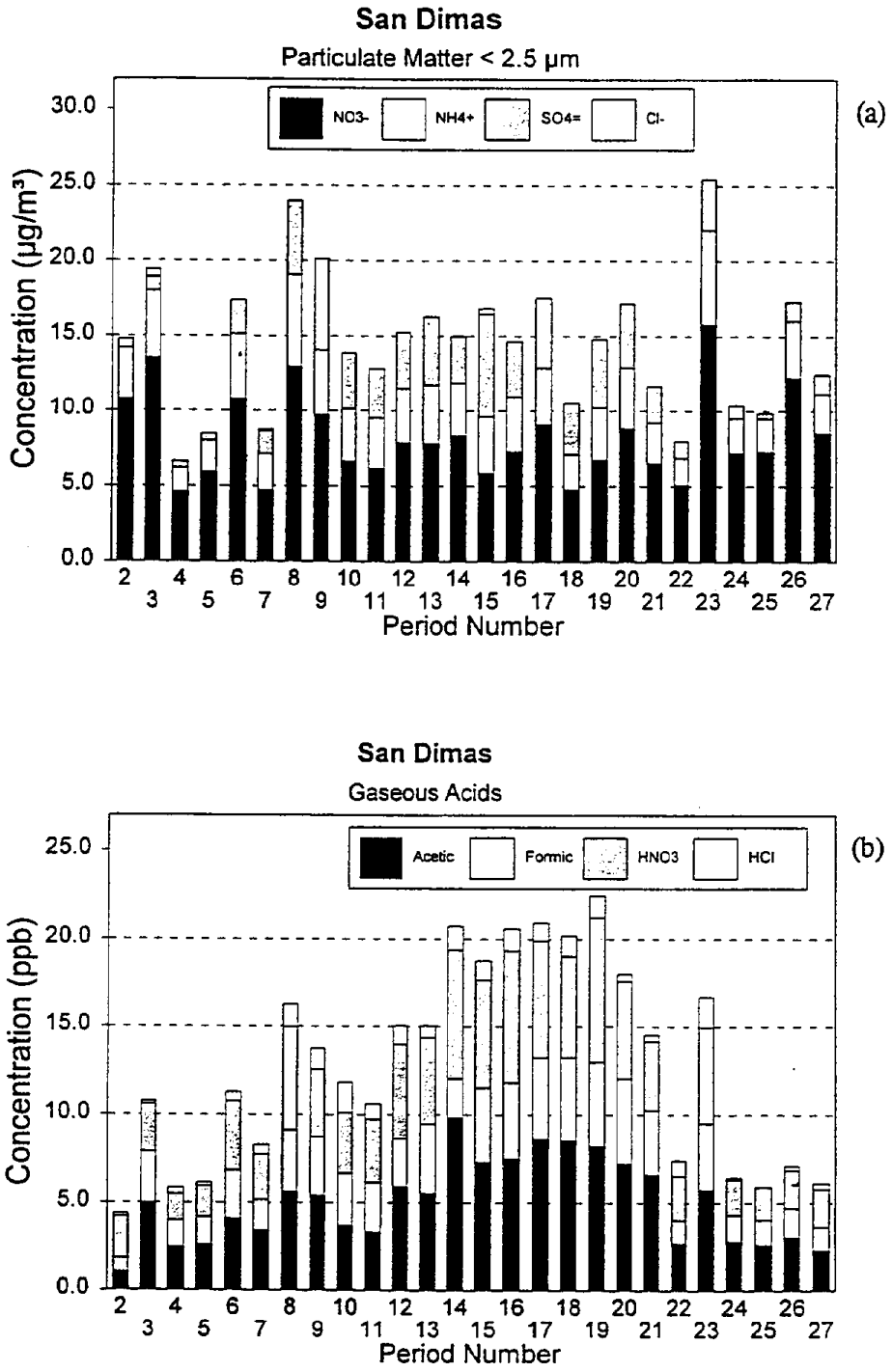


Figure 3-29. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in San Dimas.

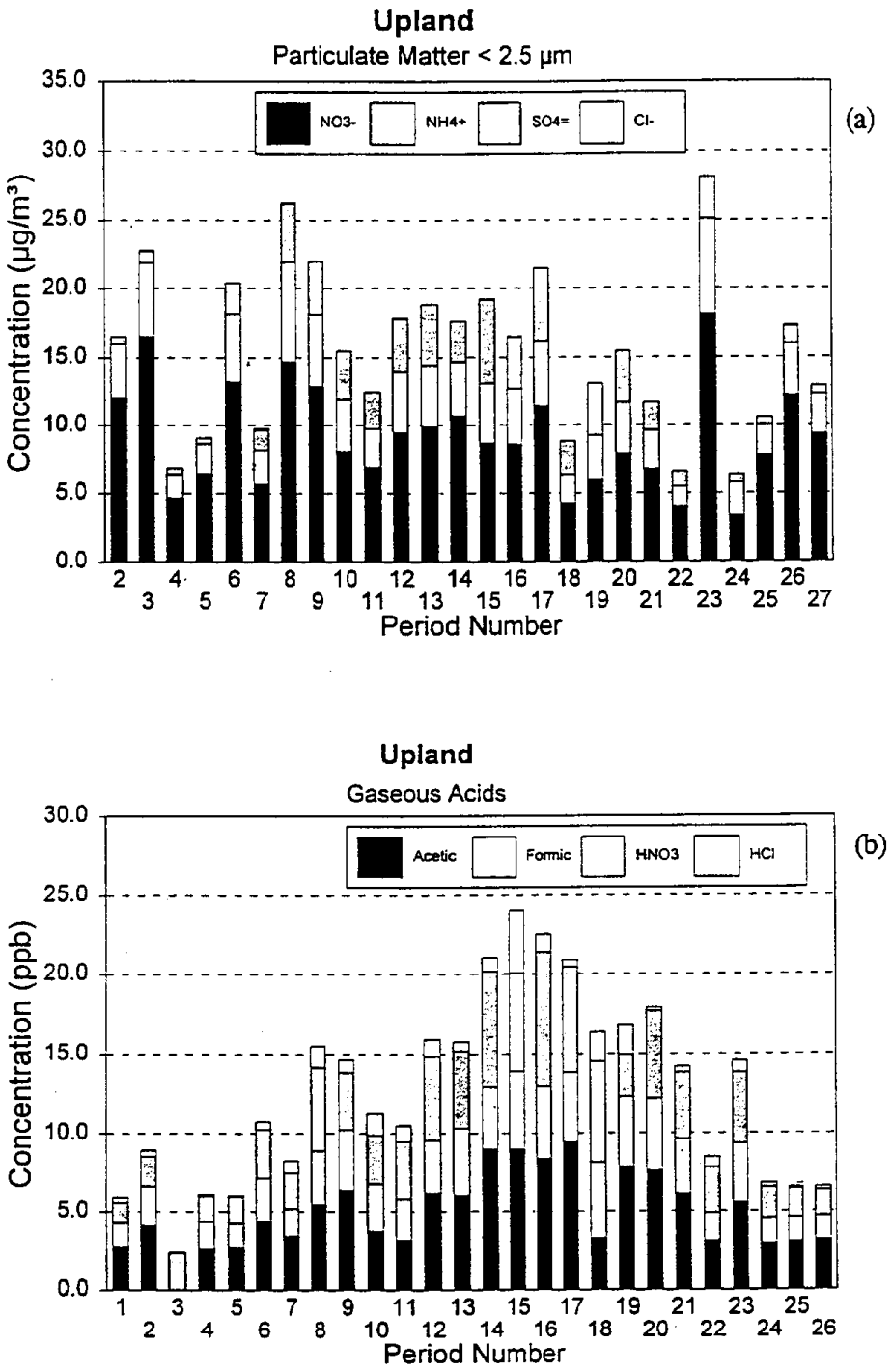


Figure 3-30. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in Upland.

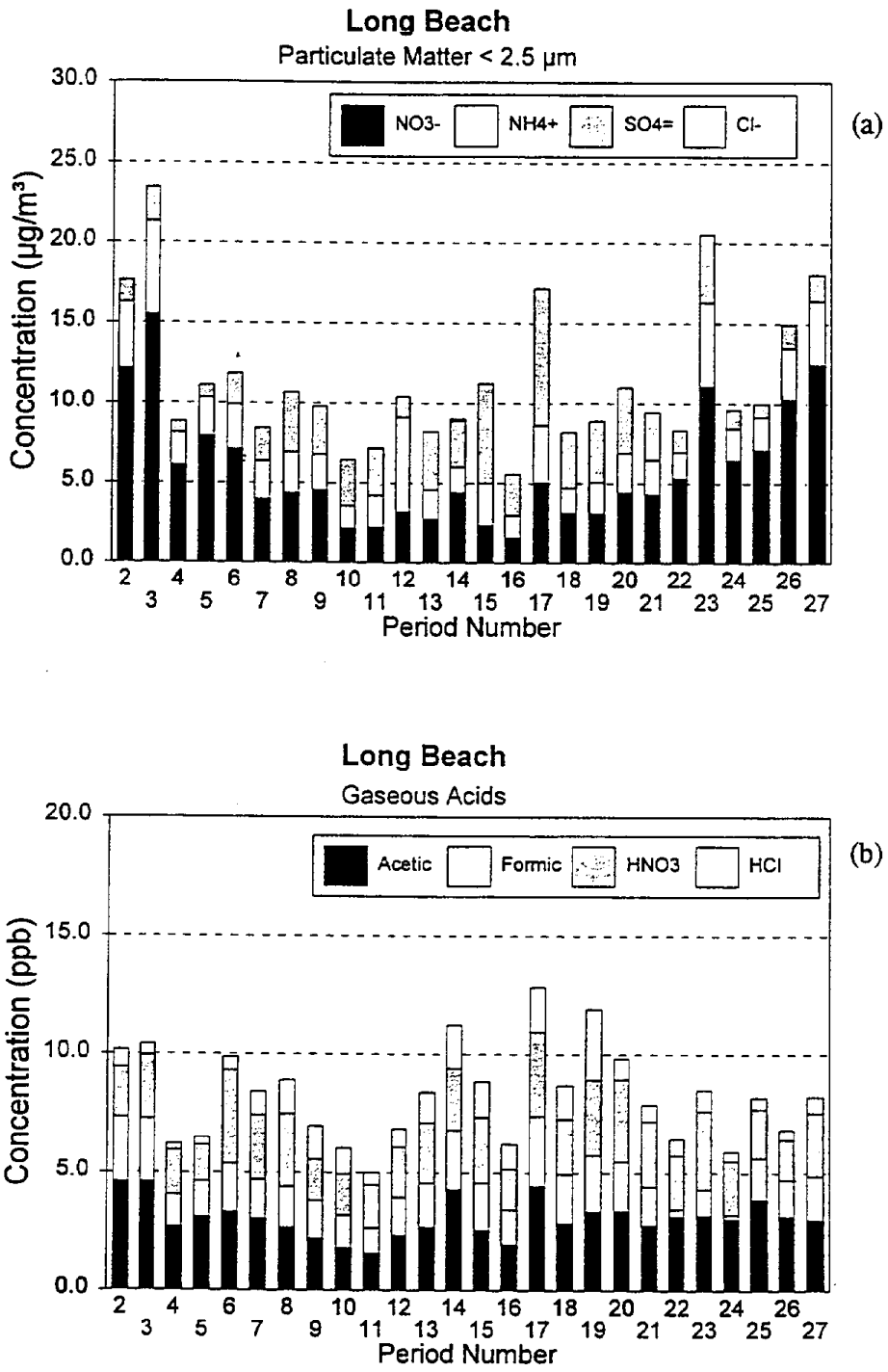


Figure 3-31. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in Long Beach.

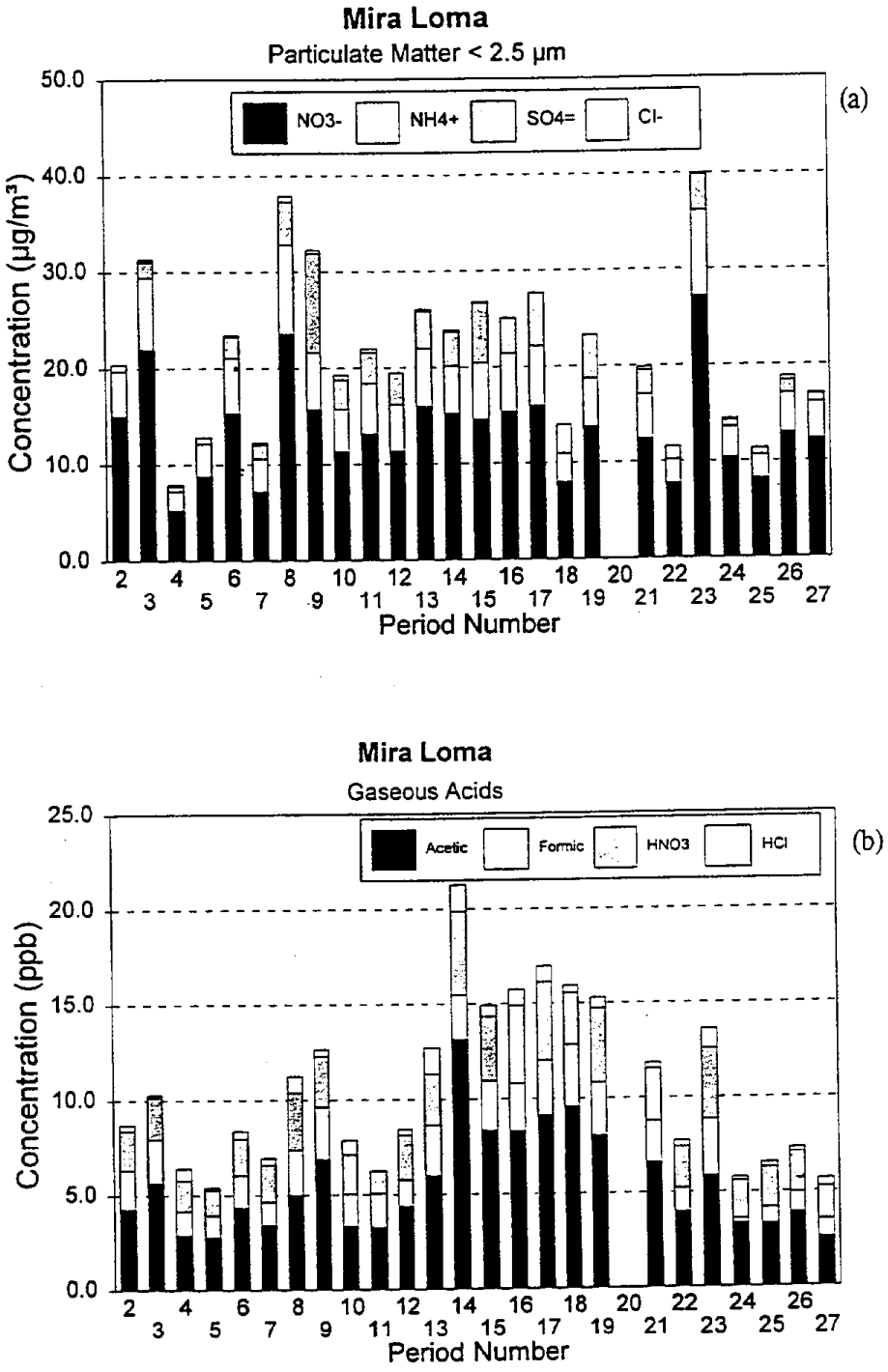


Figure 3-32. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in Mira Loma.

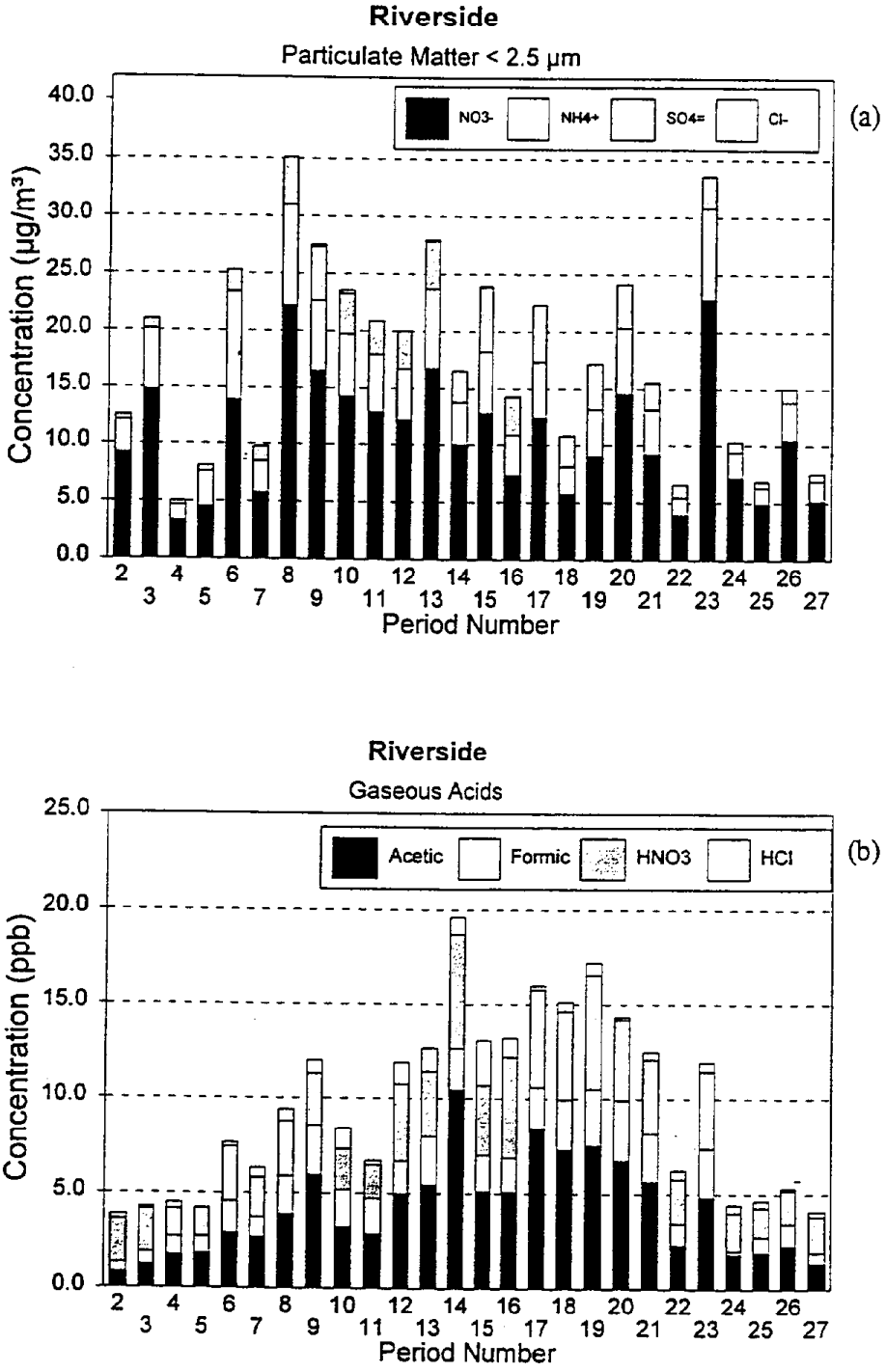


Figure 3-33. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in Riverside.

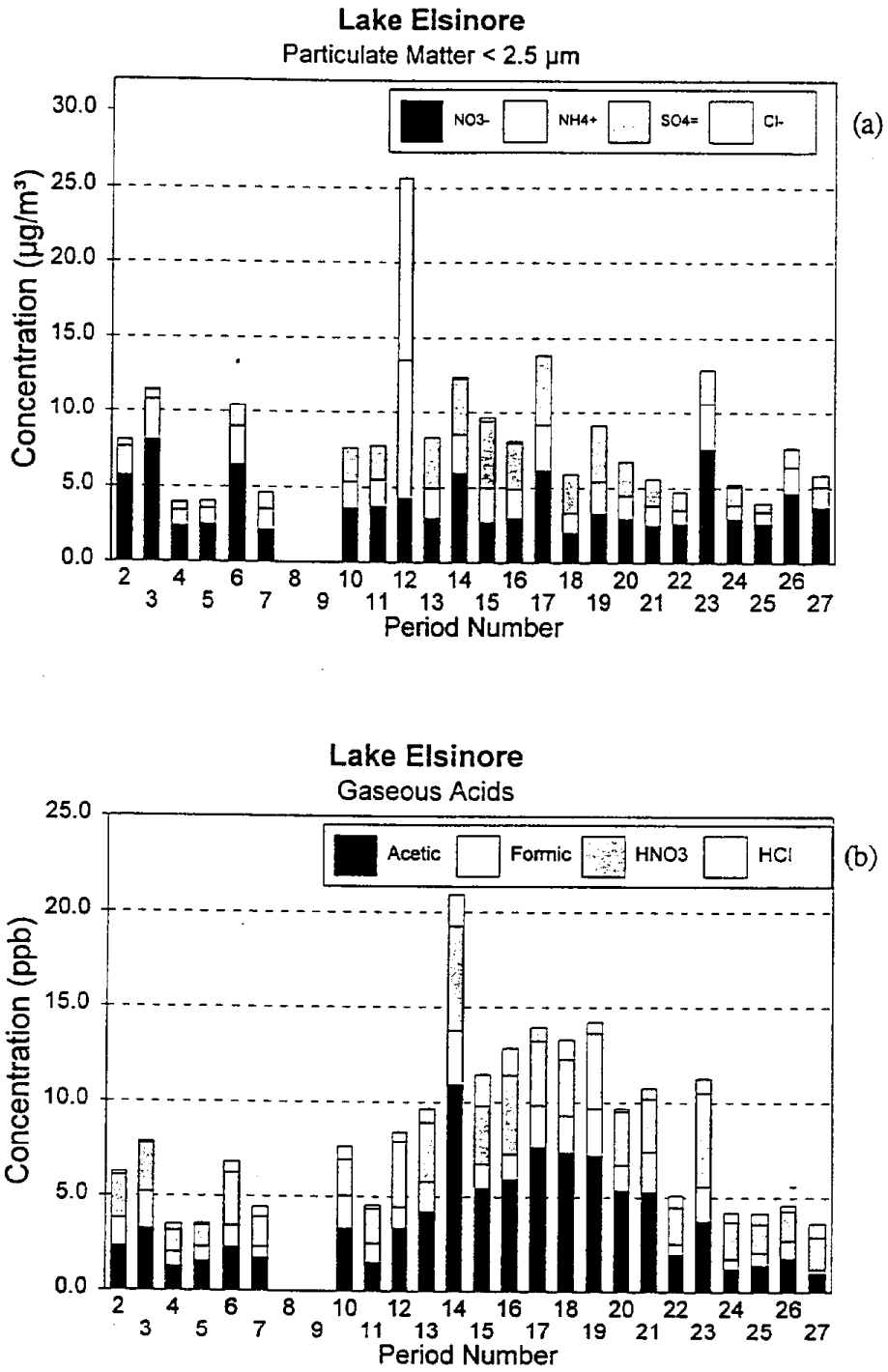


Figure 3-34. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in Lake Elsinore.

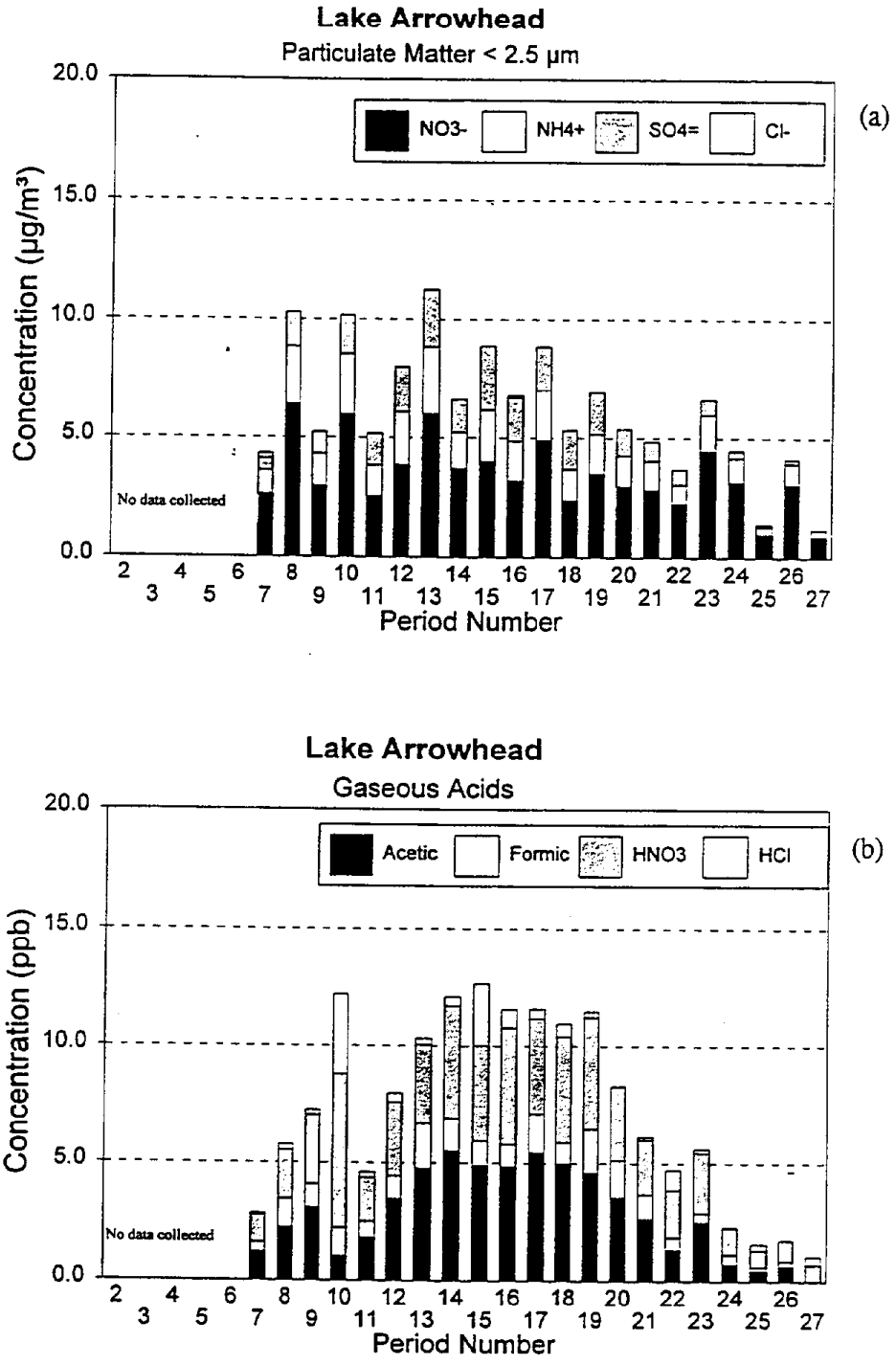


Figure 3-35. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in Lake Arrowhead.

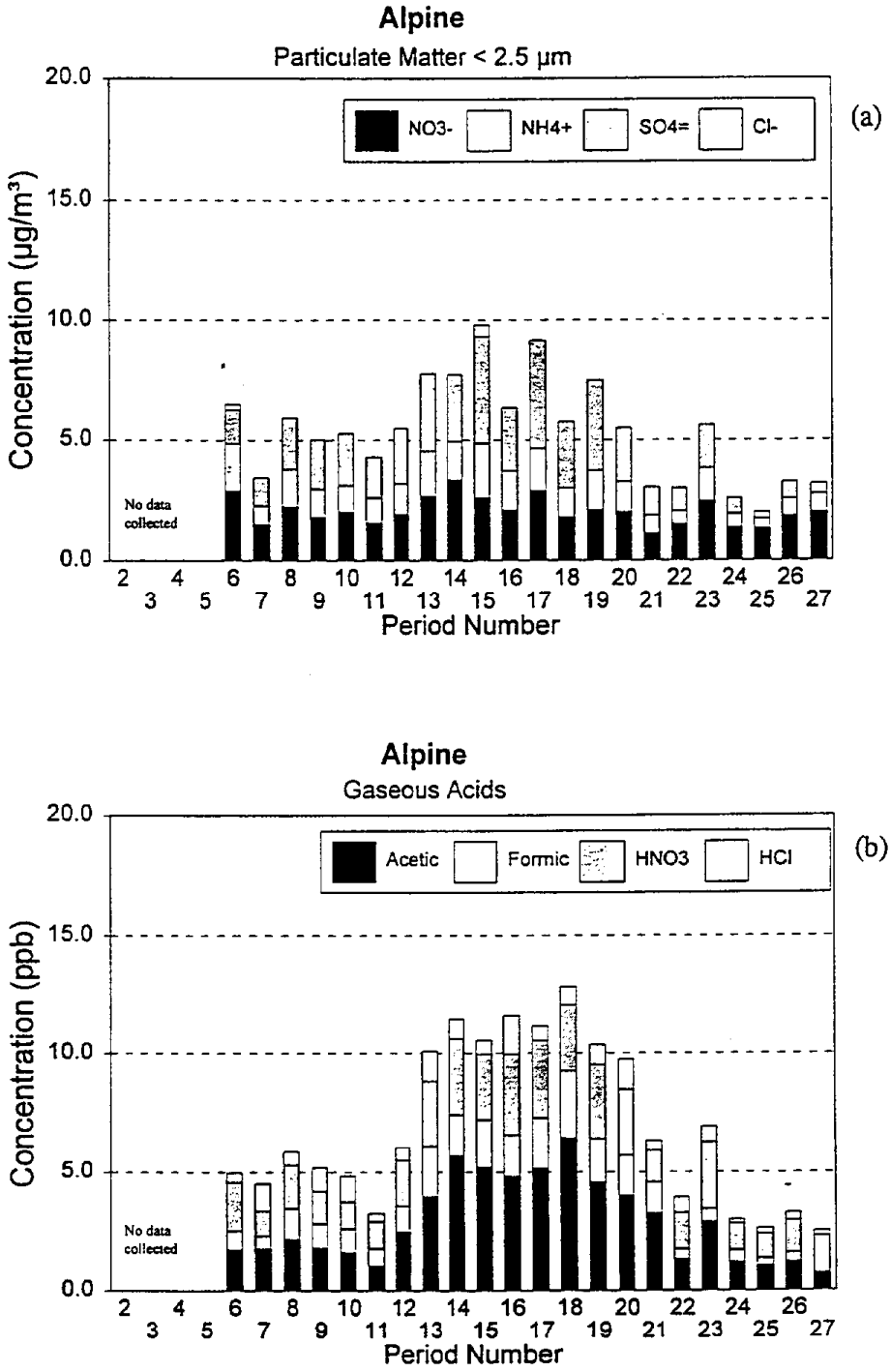


Figure 3-36. Variations in ambient concentrations of (a) $PM_{2.5}$ ions and (b) gaseous acids by 2-week sampling period in Alpine.

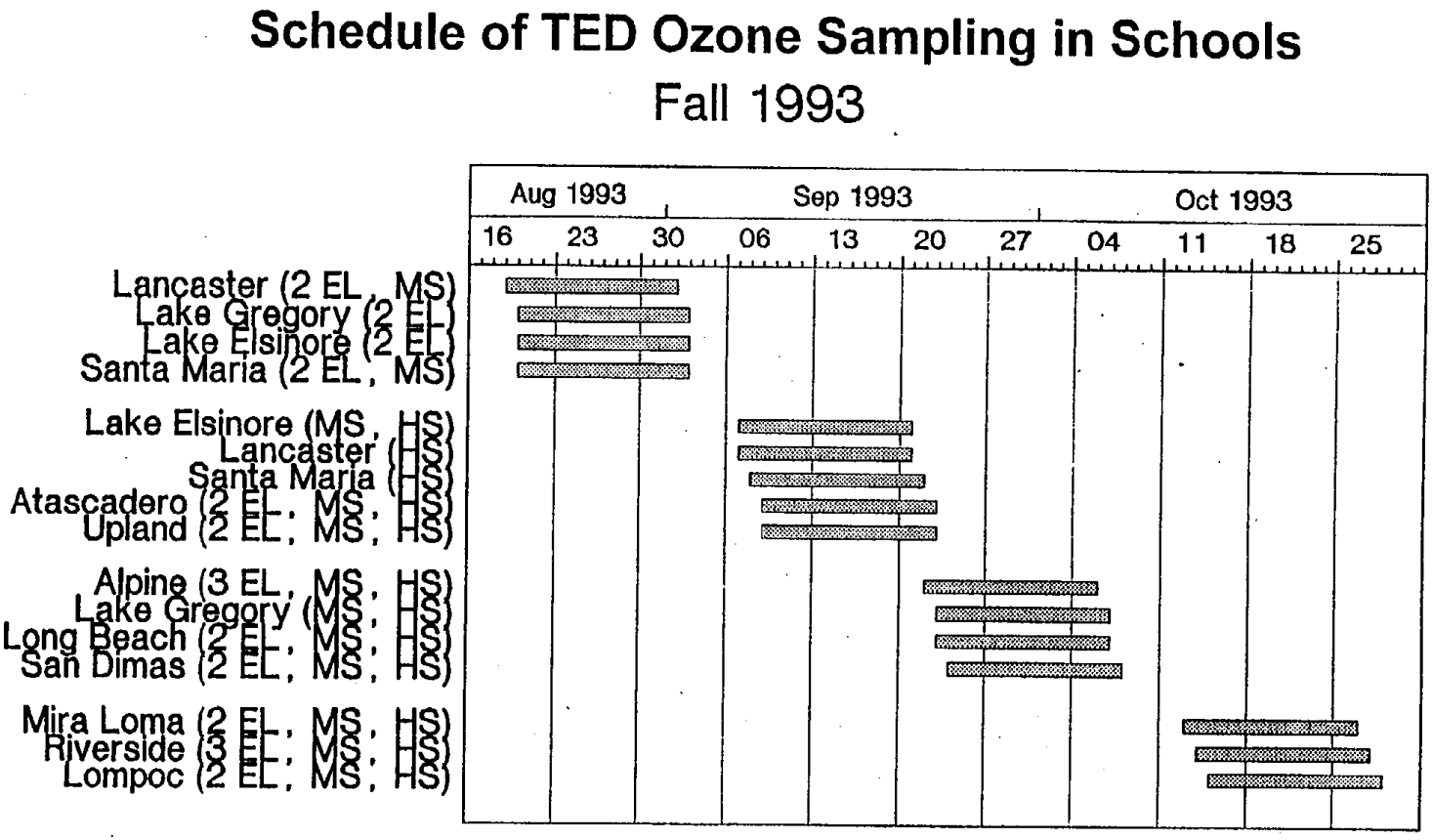


Figure 3-37. Schedule of the Fall 1993 TED ozone sampling in schools.

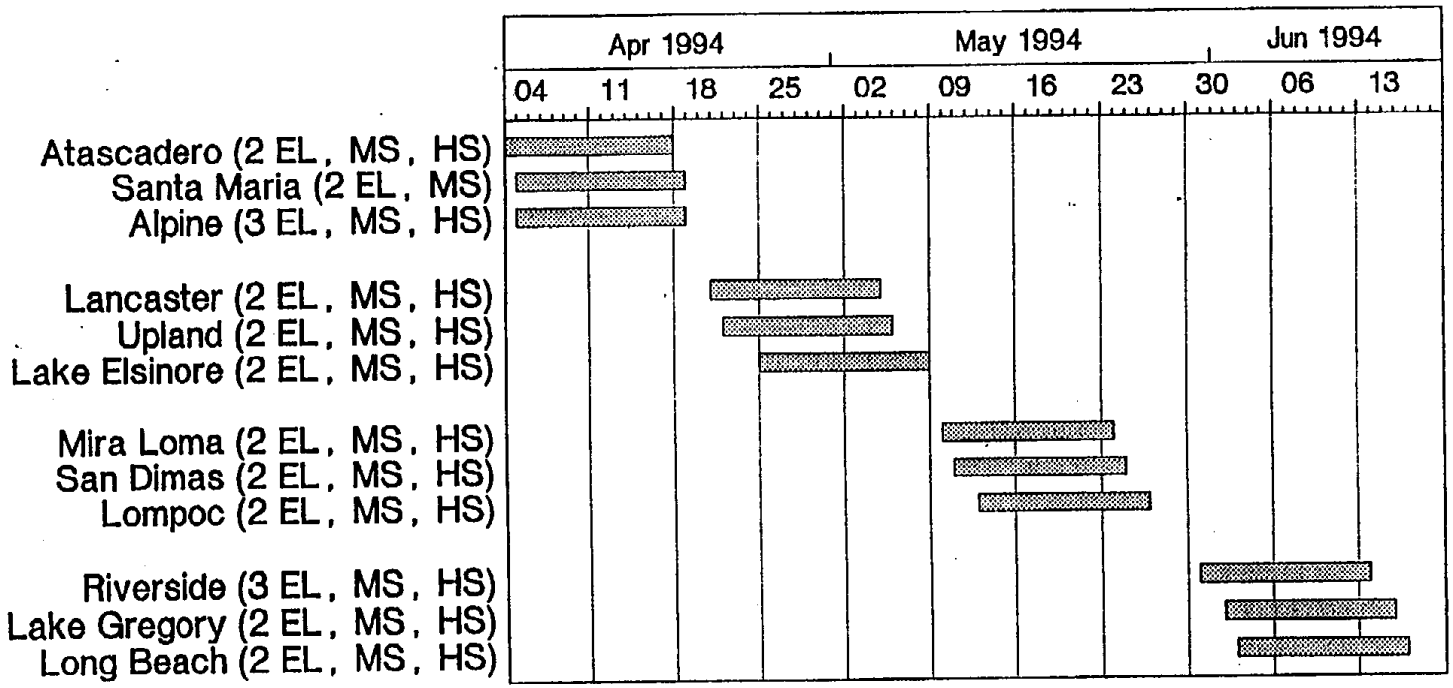


Figure 3-38. Schedule of the Spring 1994 TED ozone sampling in schools.

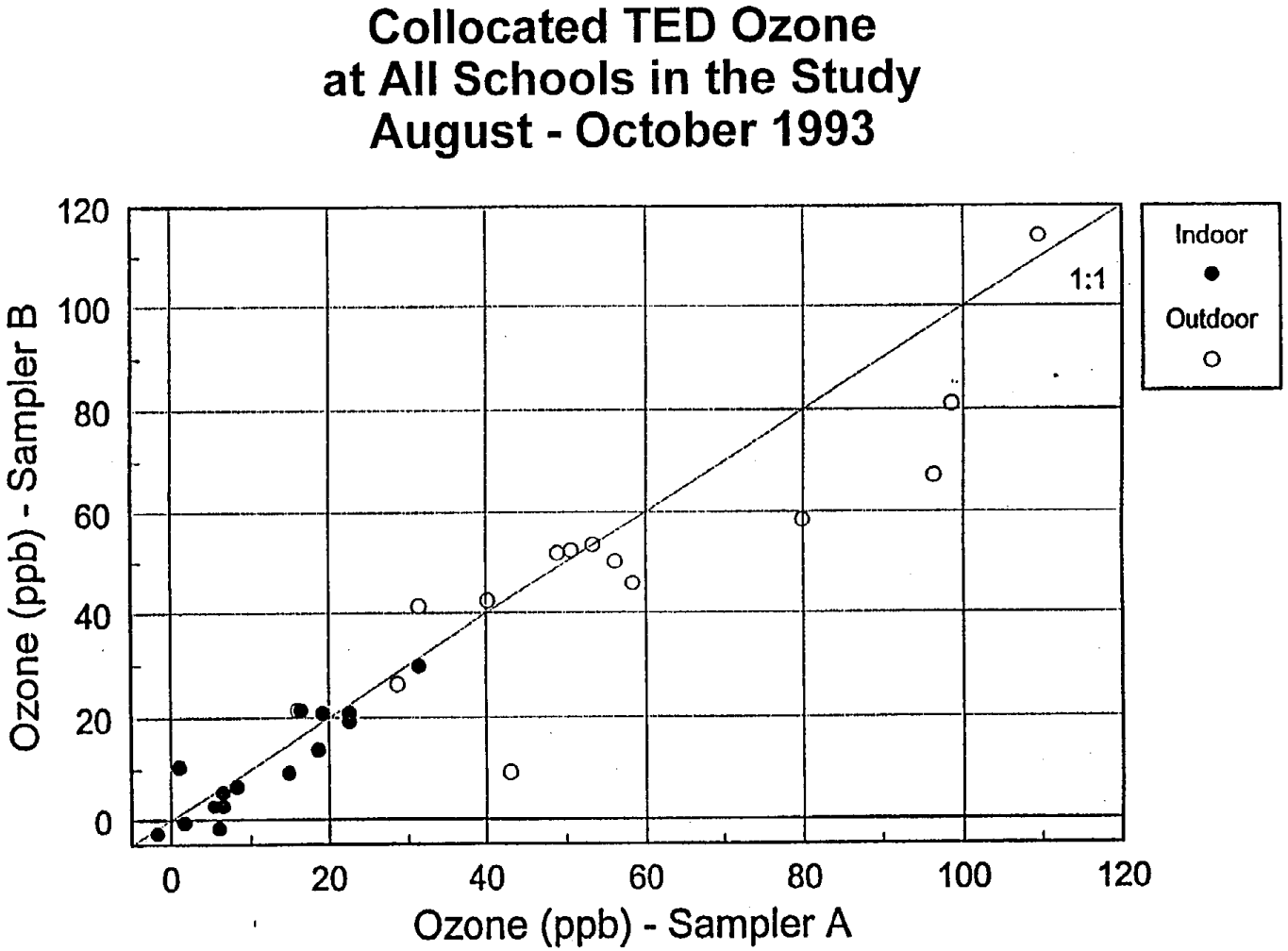


Figure 3-39. Collocated TED sampler ozone concentrations indoors and outdoor at all schools in the Fall.

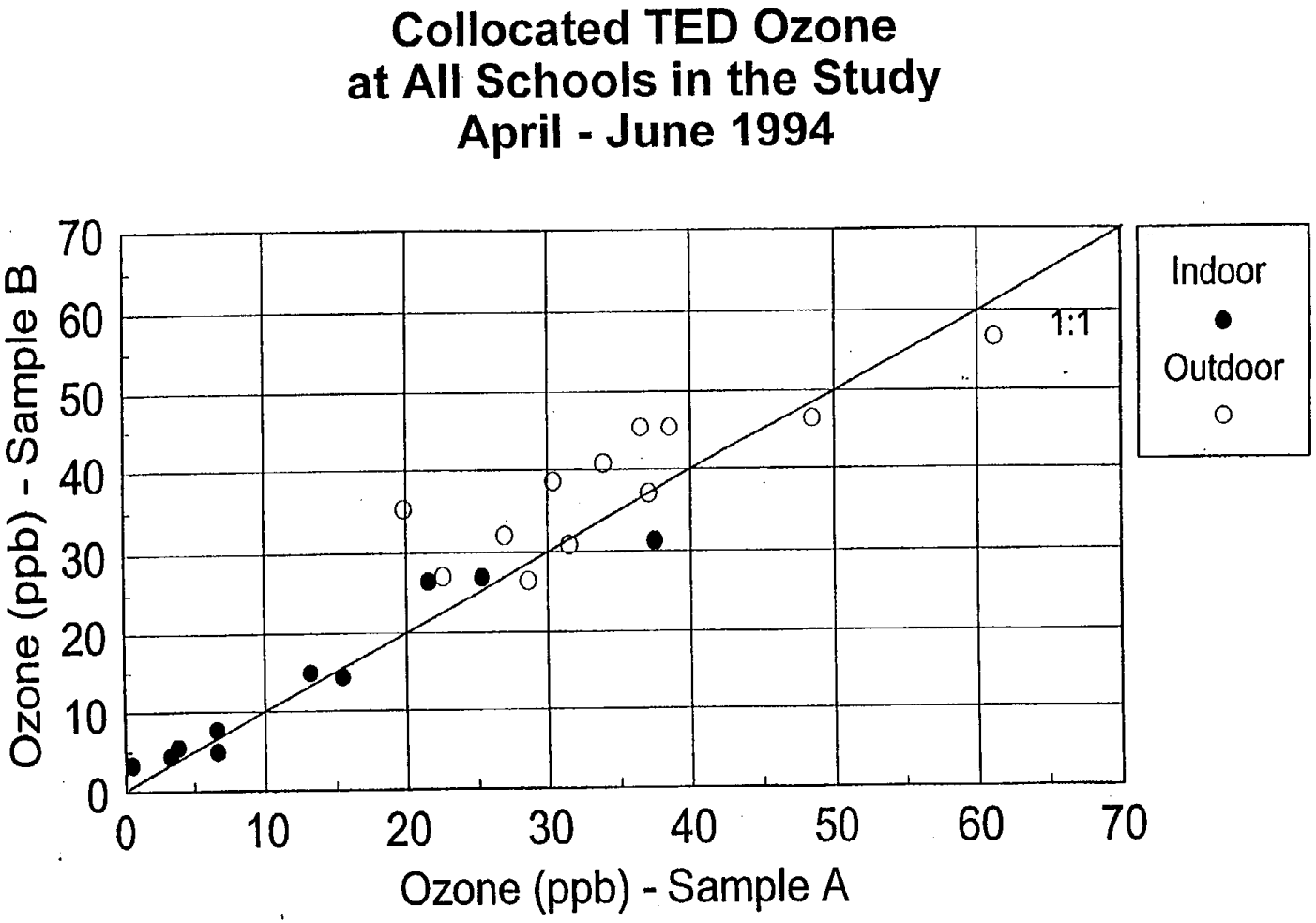


Figure 3-40. Collocated TED sampler ozone concentrations indoors and outdoor at all schools in the Spring.

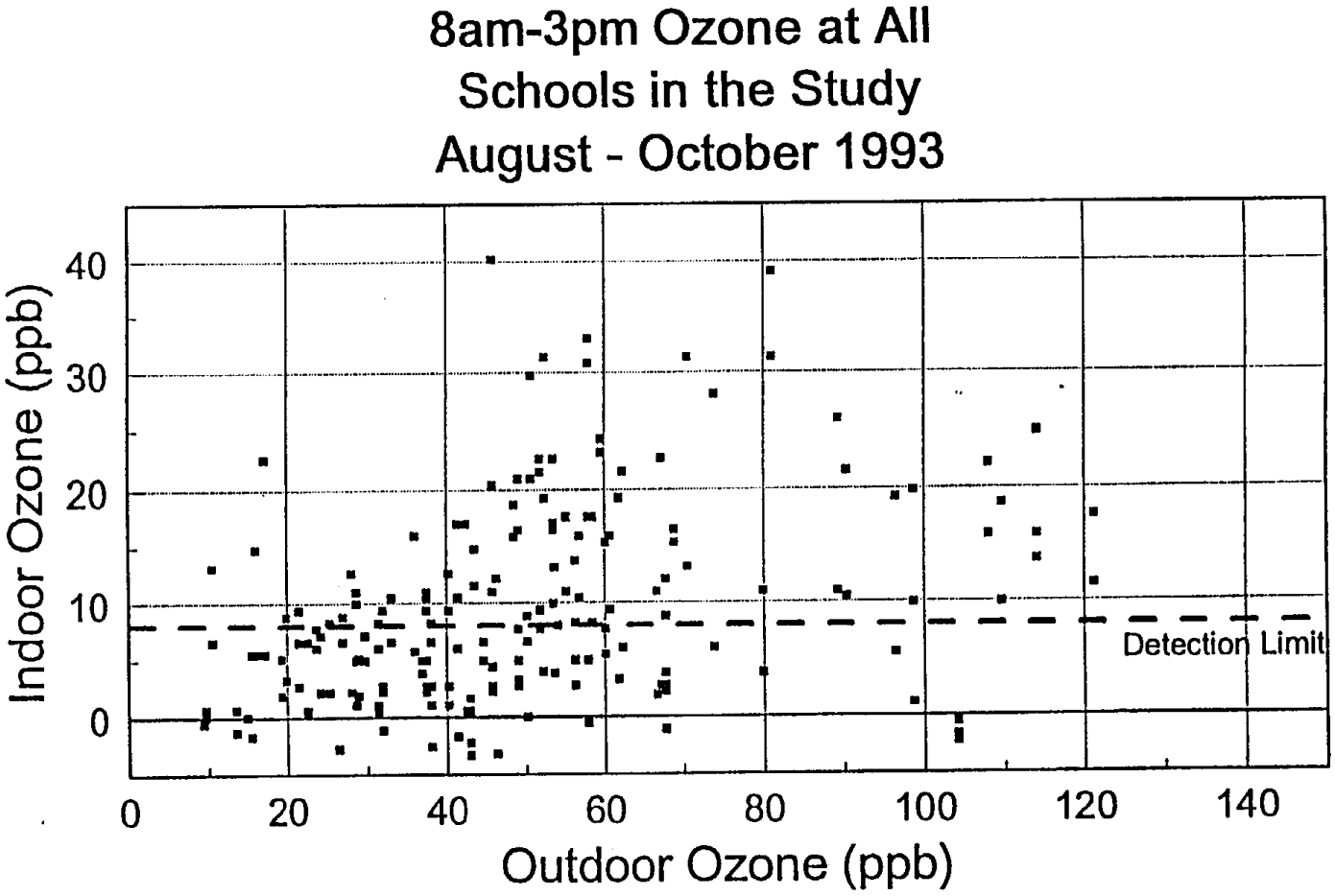


Figure 3-41. Scatter plot of indoor versus outdoor TED sampler ozone concentrations at all schools in the Fall.

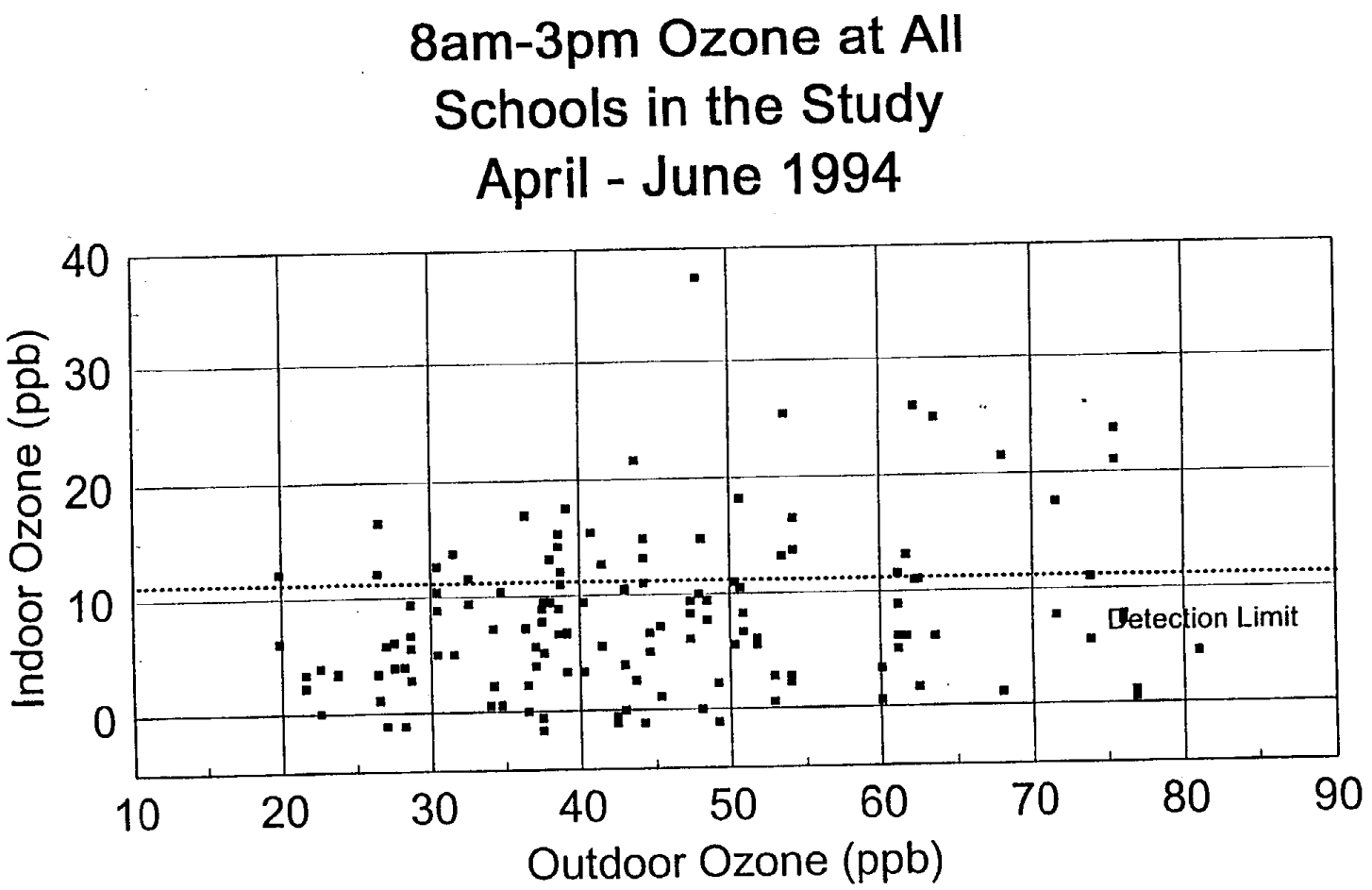


Figure 3-42. Scatter plot of indoor versus outdoor TED sampler ozone concentrations at all schools in the Spring.

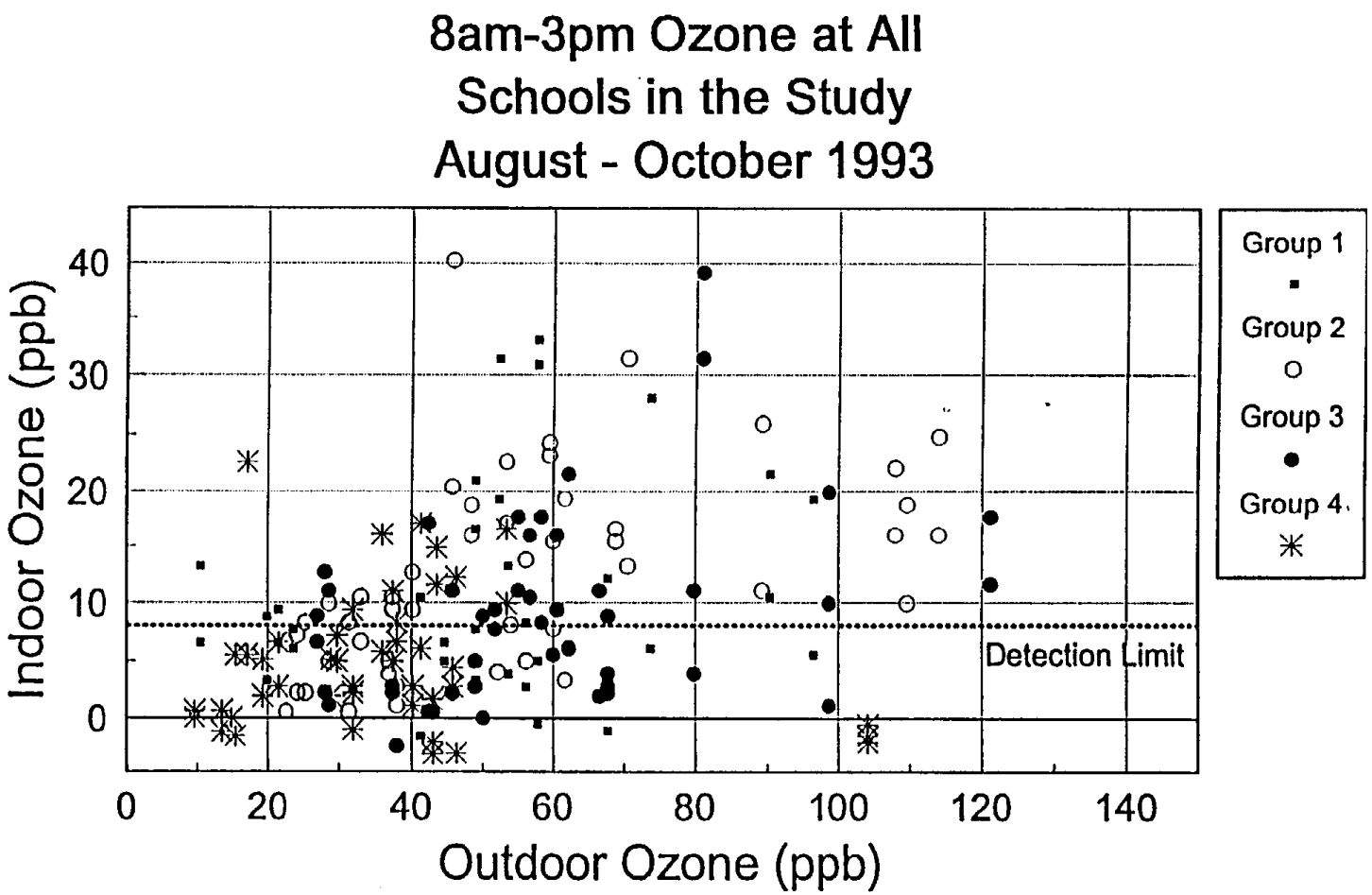


Figure 3-43. Scatter plot of indoor versus outdoor TED sampler ozone concentrations at all schools in the Fall in the four sampling periods (groups 1 to 4).

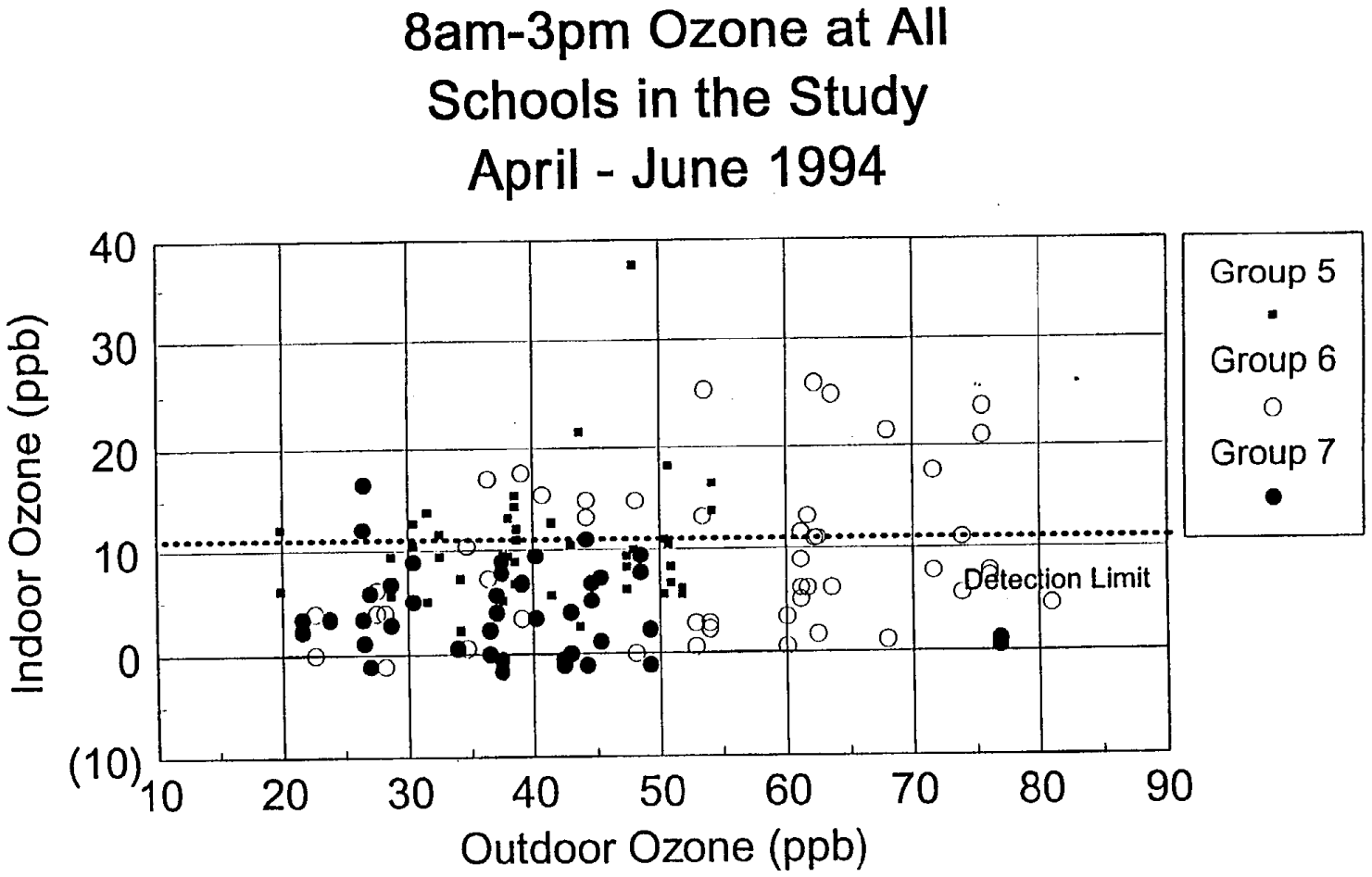


Figure 3-44. Scatter plot of indoor versus outdoor TED sampler ozone concentrations at all schools in the Spring in the three sampling periods.

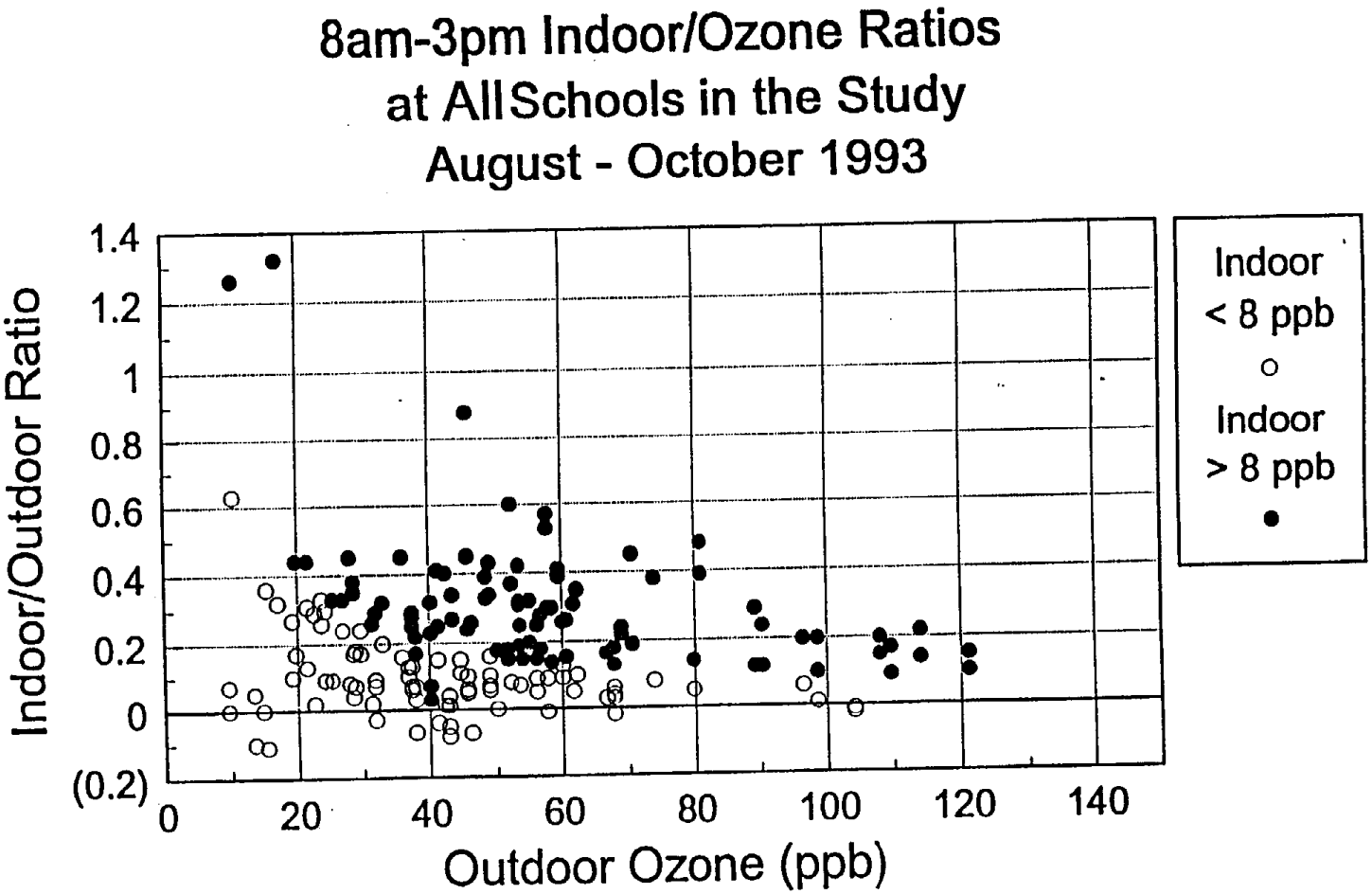


Figure 3-45. Scatter plot of the indoor/outdoor ratio versus the outdoor TED sampler ozone concentrations at all schools in the Fall. Ratios calculated for cases with indoor concentrations below the 8 ppb limit of detection are approximate.

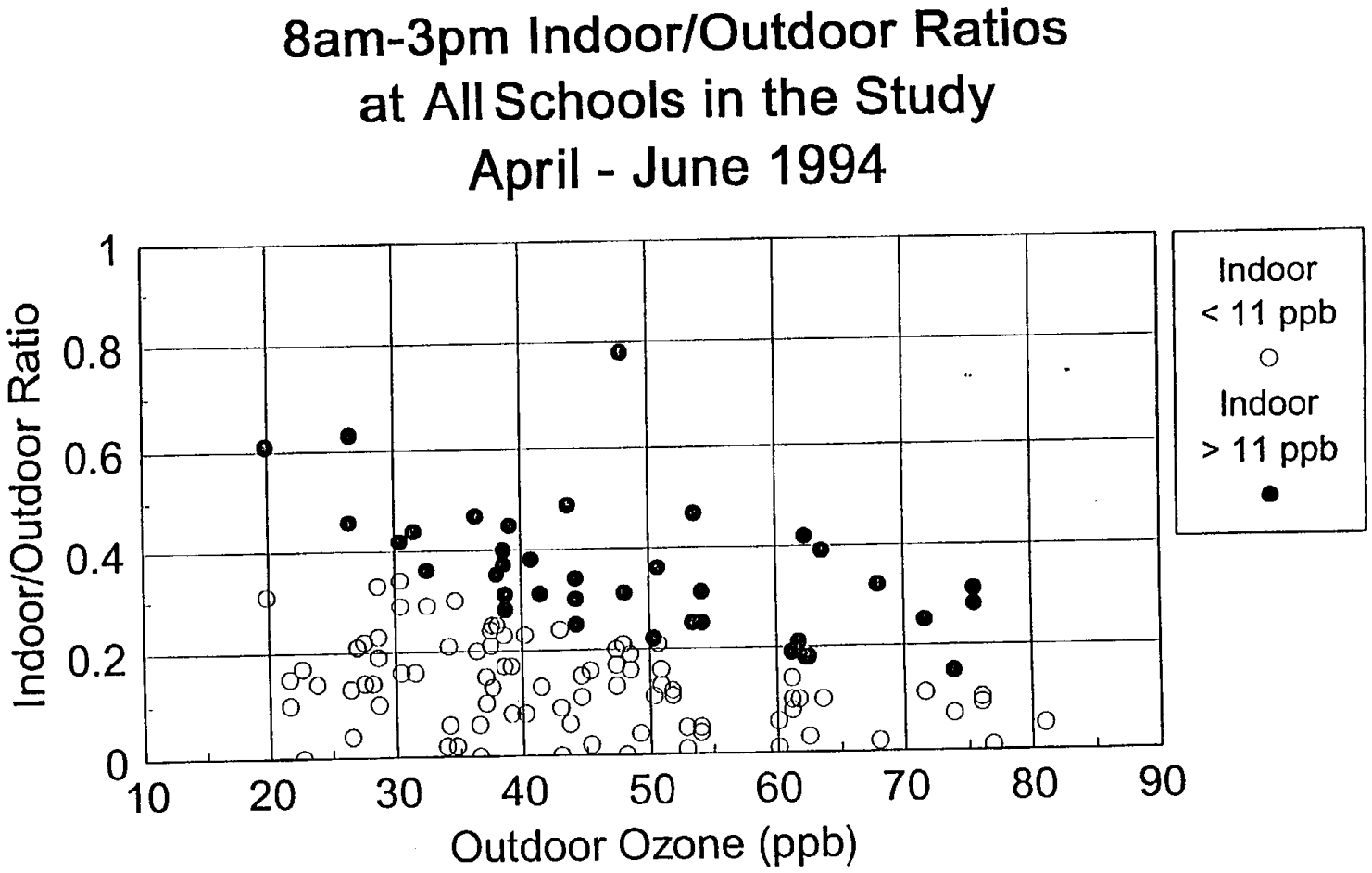


Figure 3-46. Scatter plot of the indoor/outdoor ratio versus the outdoor TED sampler ozone concentrations at all schools in the Spring. Ratios calculated for cases with indoor concentrations below the 11 ppb detection are approximate.

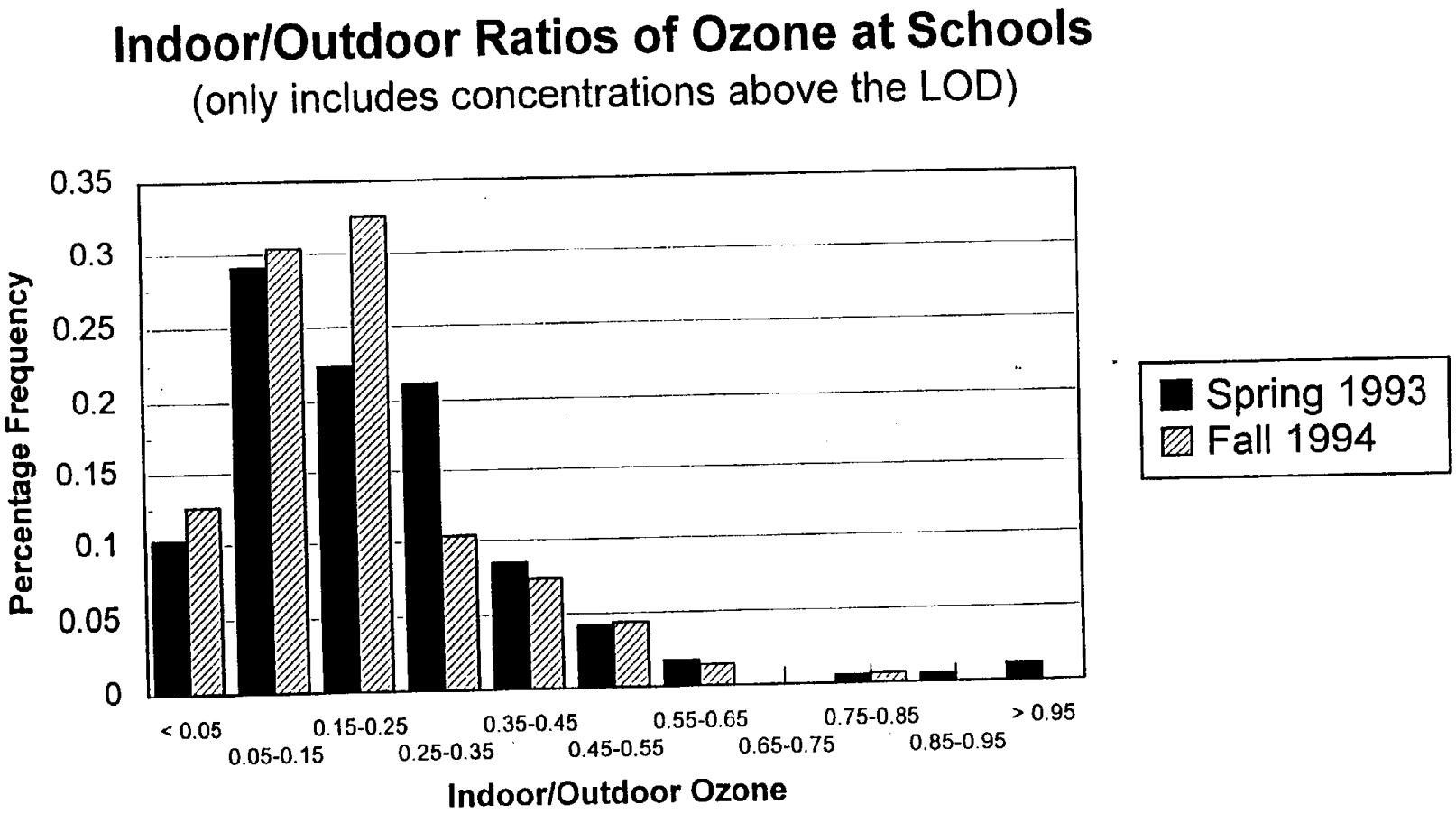


Figure 3-47. Histogram of indoor/outdoor ozone concentration ratios for Spring 1993 and Fall 1994.

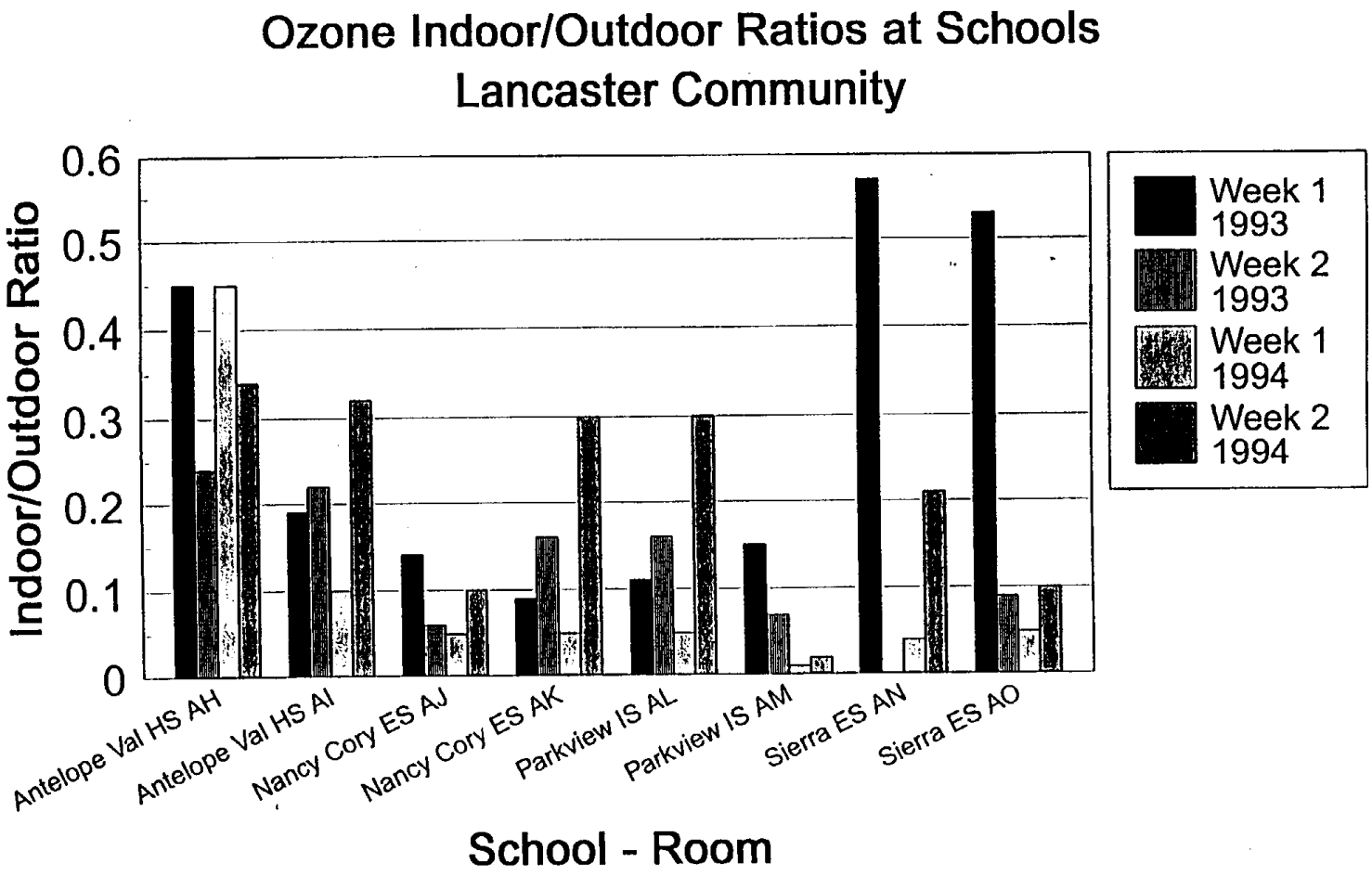


Figure 3-48. Comparison of samples collected in the same rooms in Lancaster schools.

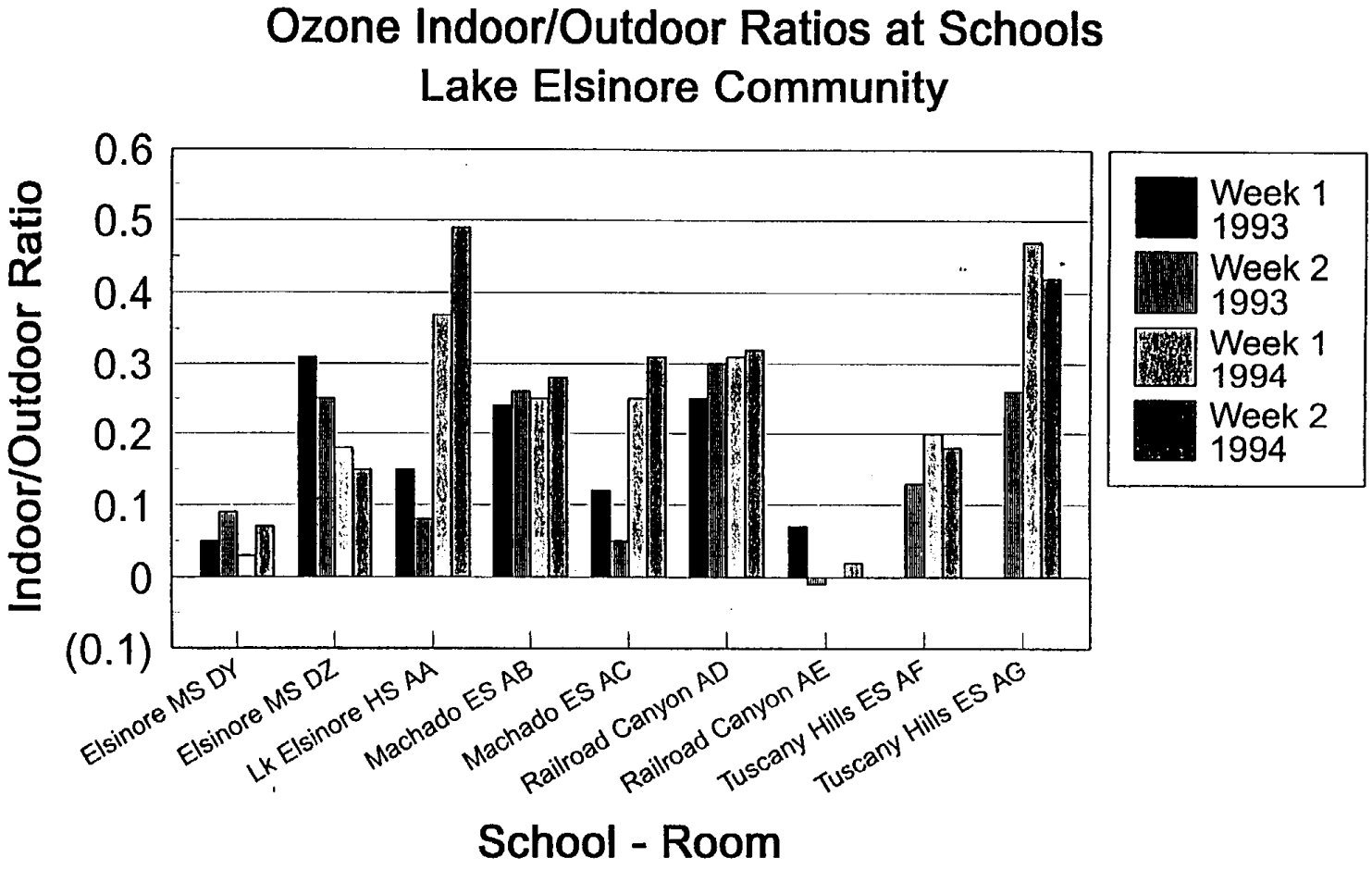


Figure 3-49. Comparison of samples collected in the same rooms in Lake Elsinore schools.

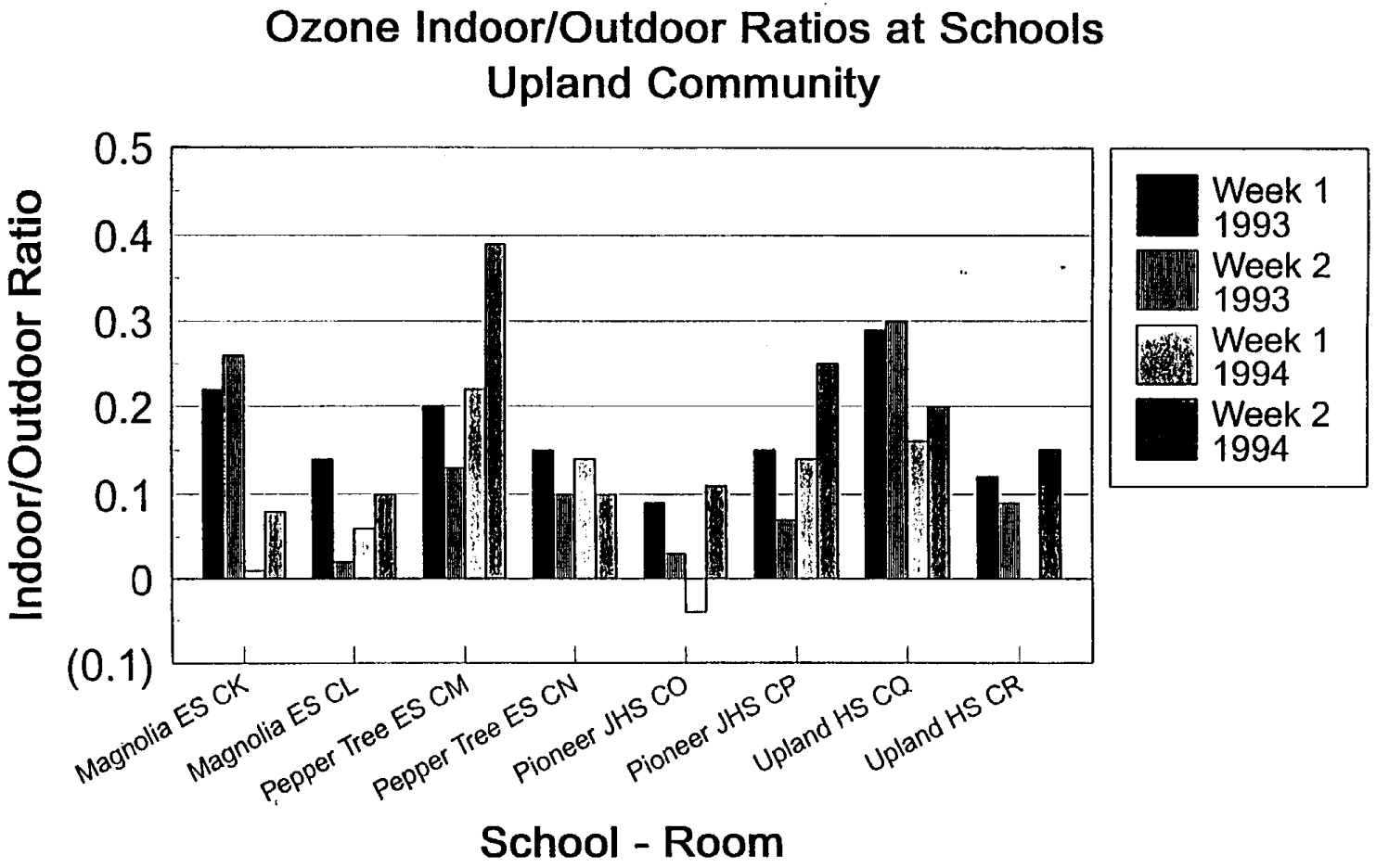


Figure 3-50. Comparison of samples collected in the same rooms in Upland schools.

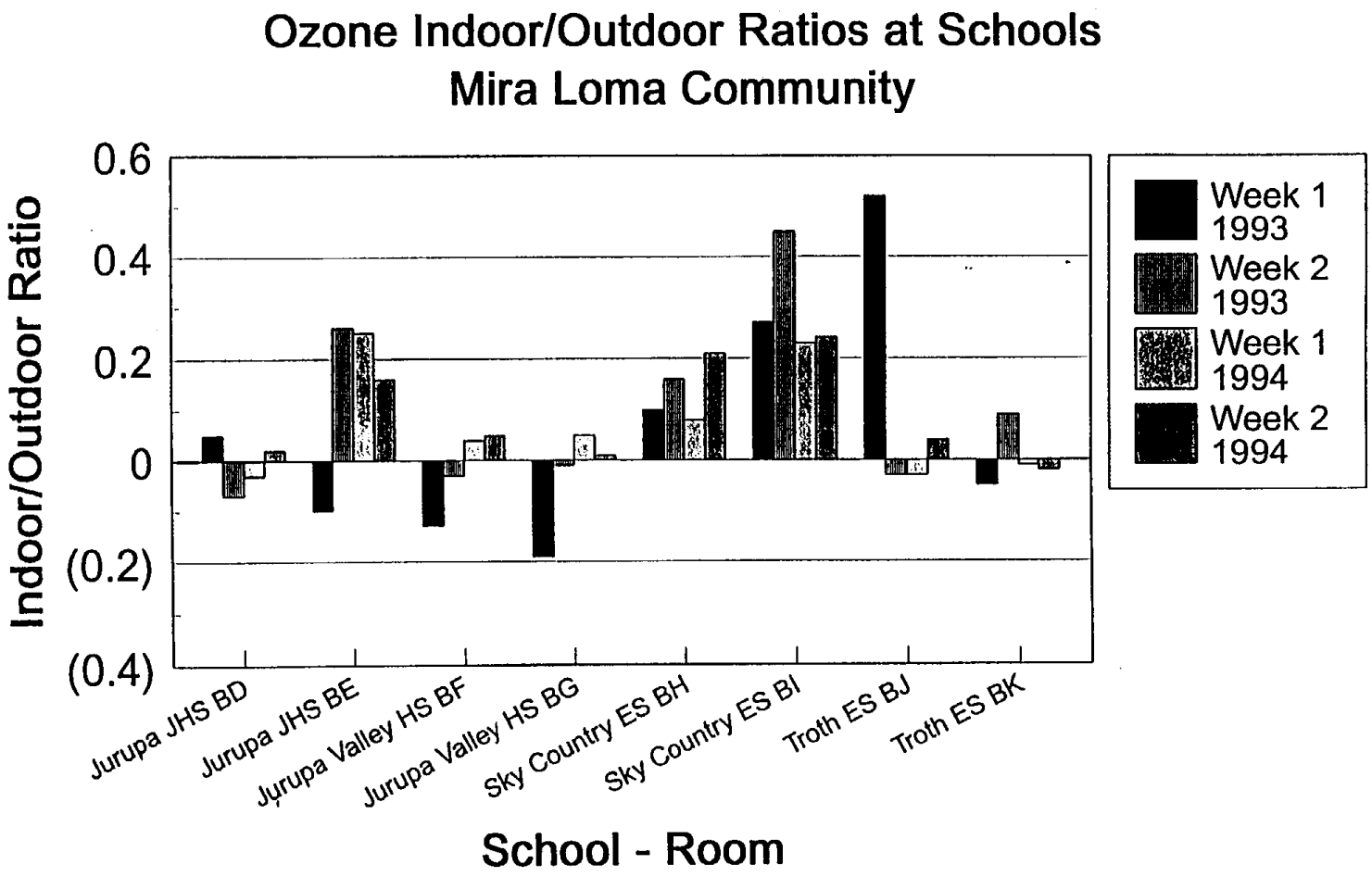


Figure 3-51. Comparison of samples collected in the same rooms in Mira Loma schools.

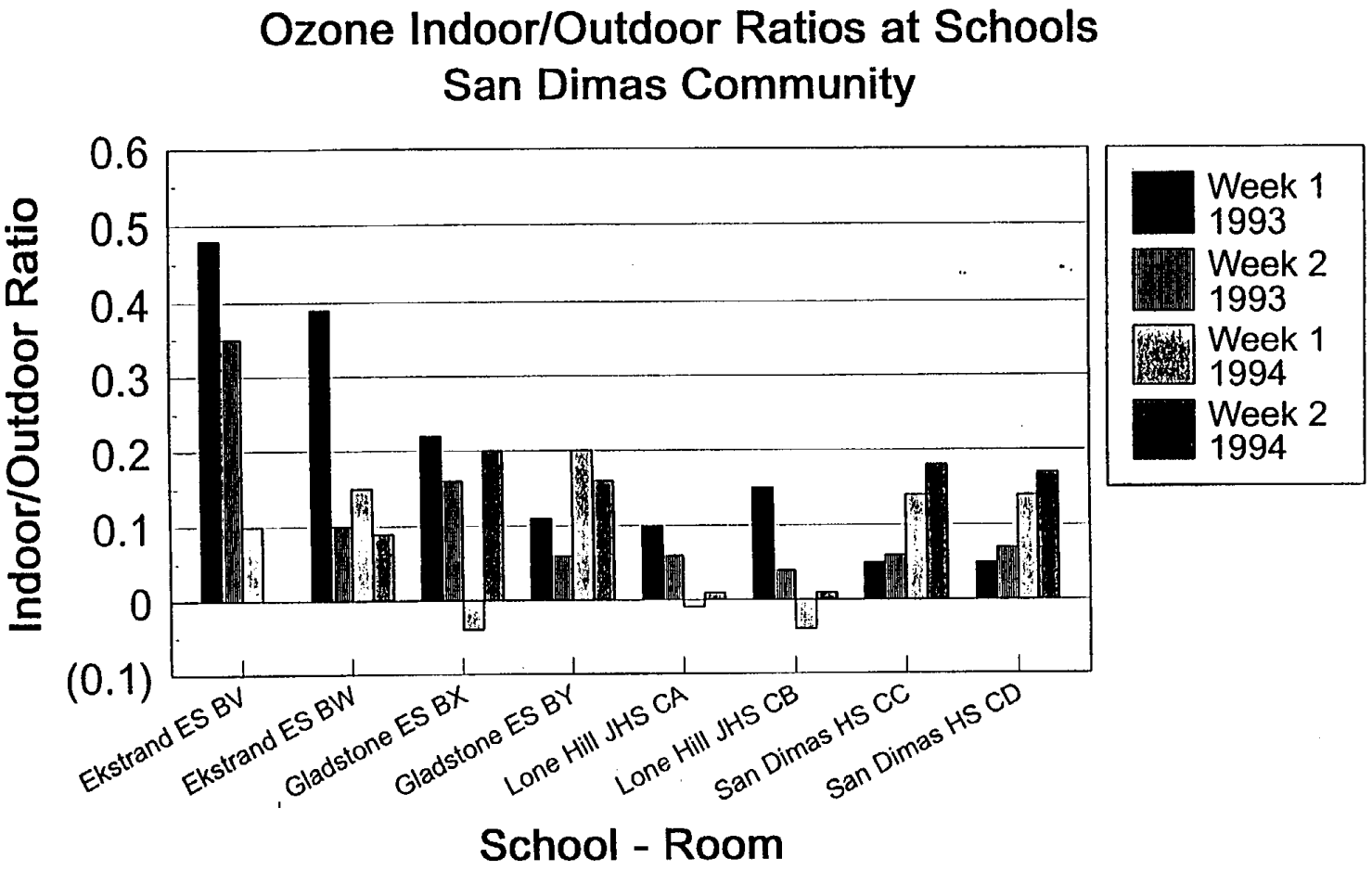


Figure 3-52. Comparison of samples collected in the same rooms in San Dimas schools.

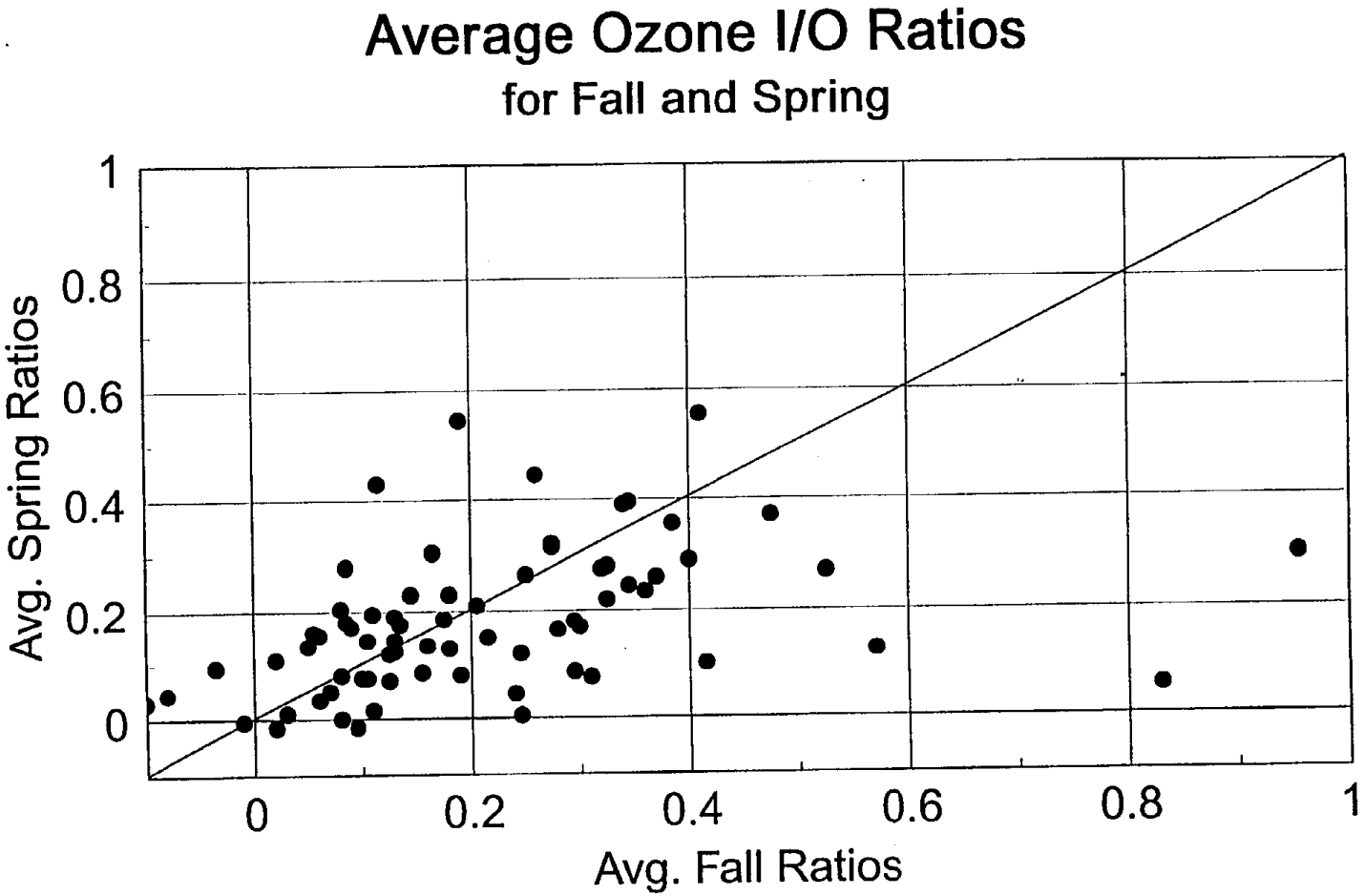


Figure 3-53. Scatter plot of average Fall I/O ratios versus average Spring I/O ratios for ozone at all schools.

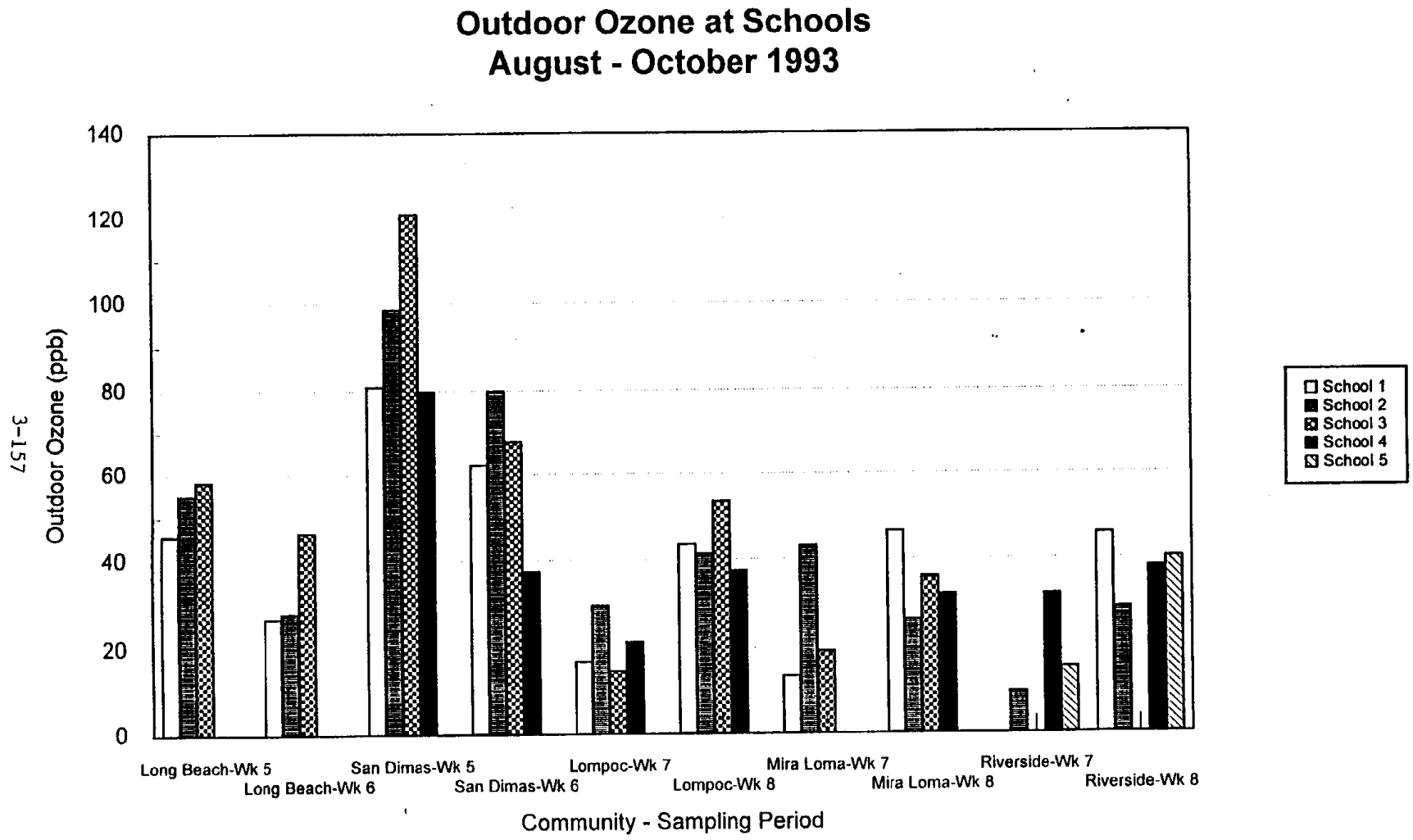


Figure 3-54. Comparison of the 8:00 a.m. to 3:00 p.m. integrated ozone concentrations outdoors at selected schools in the Fall.

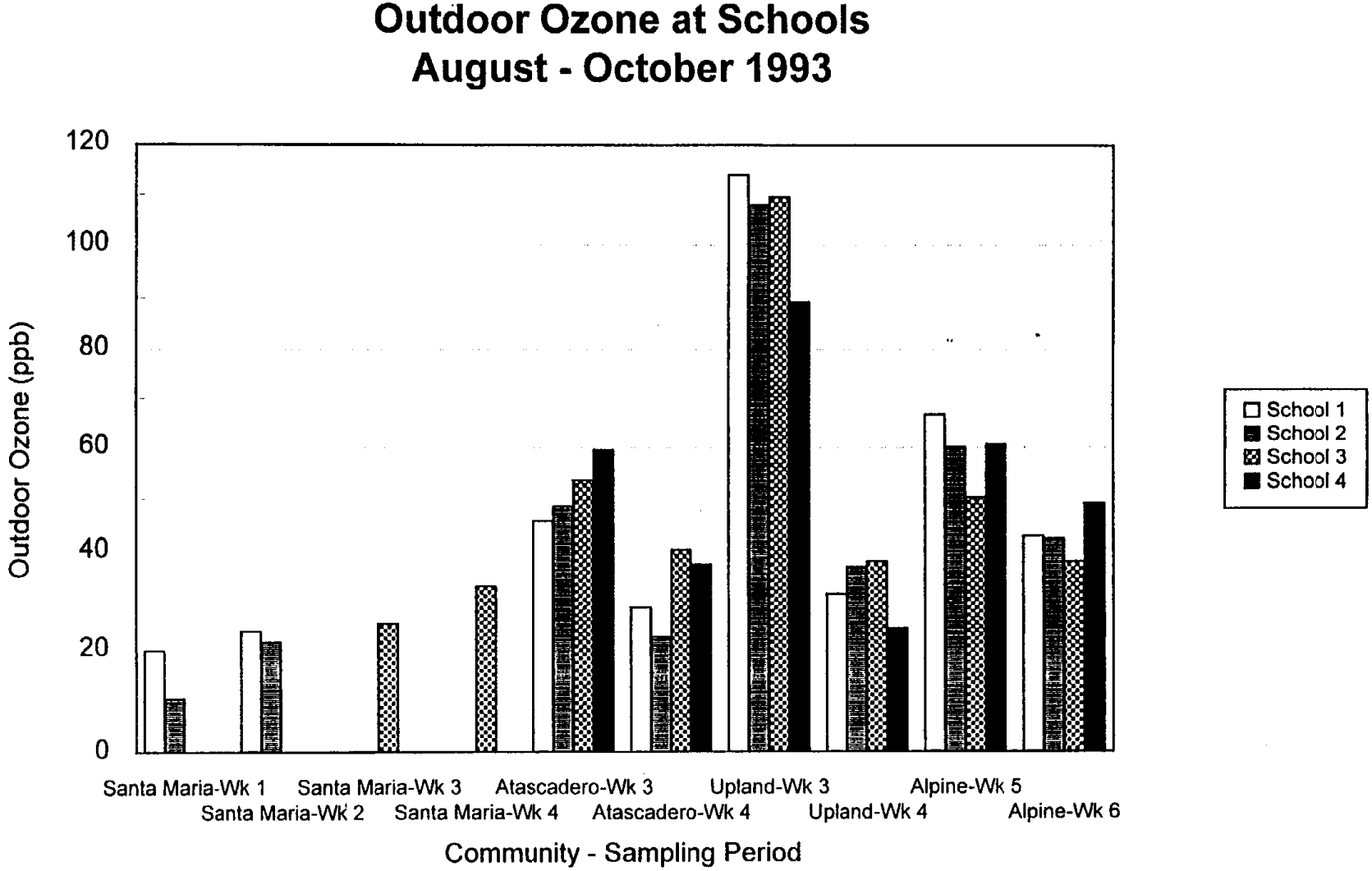


Figure 3-55. Comparison of the 8:00 a.m. to 3:00 p.m. integrated ozone concentrations outdoors at selected schools in the Fall.

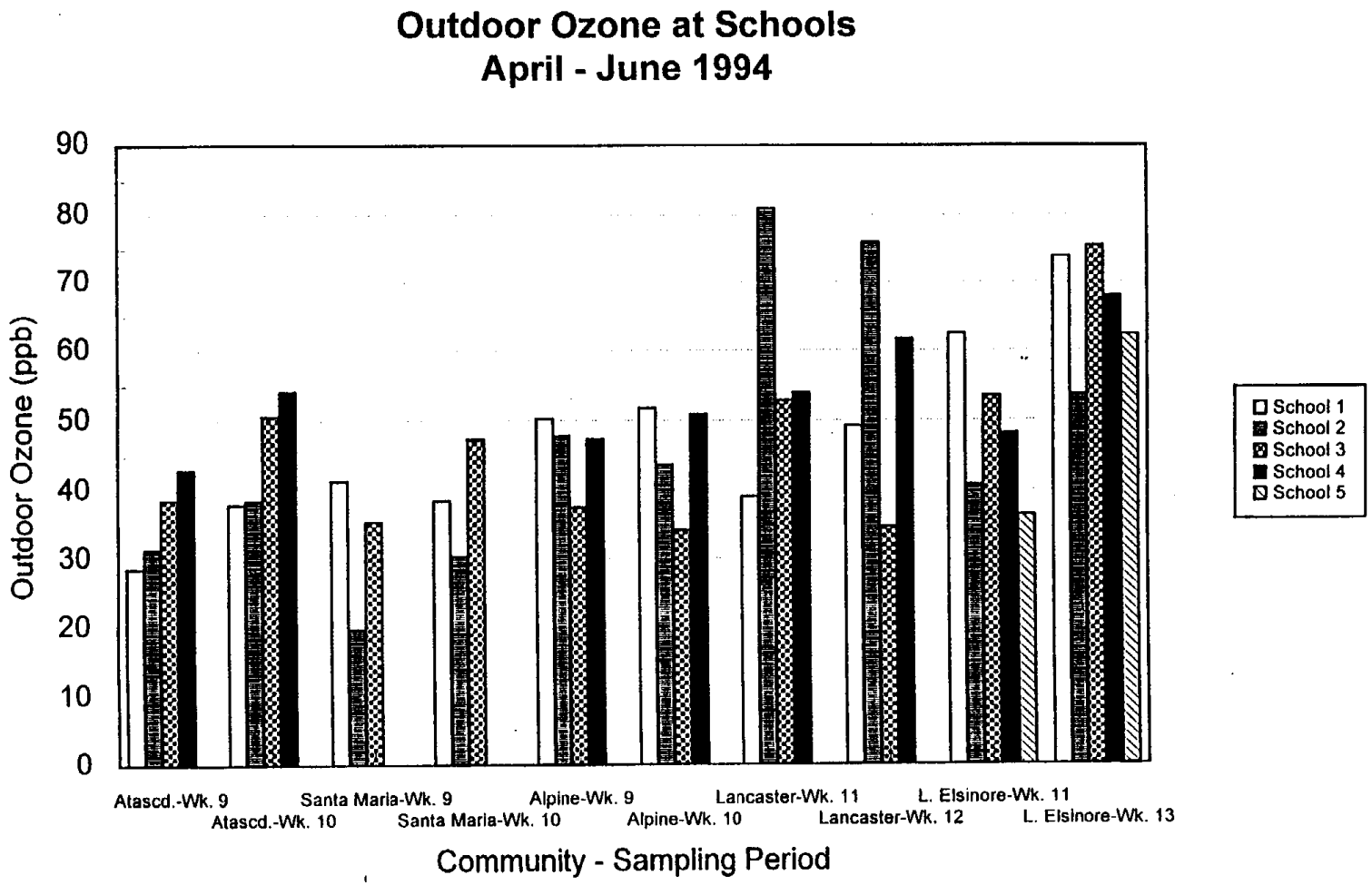


Figure 3-56. Comparison of the 8:00 a.m. to 3:00 p.m. integrated ozone concentrations outdoors at selected schools in the Spring.

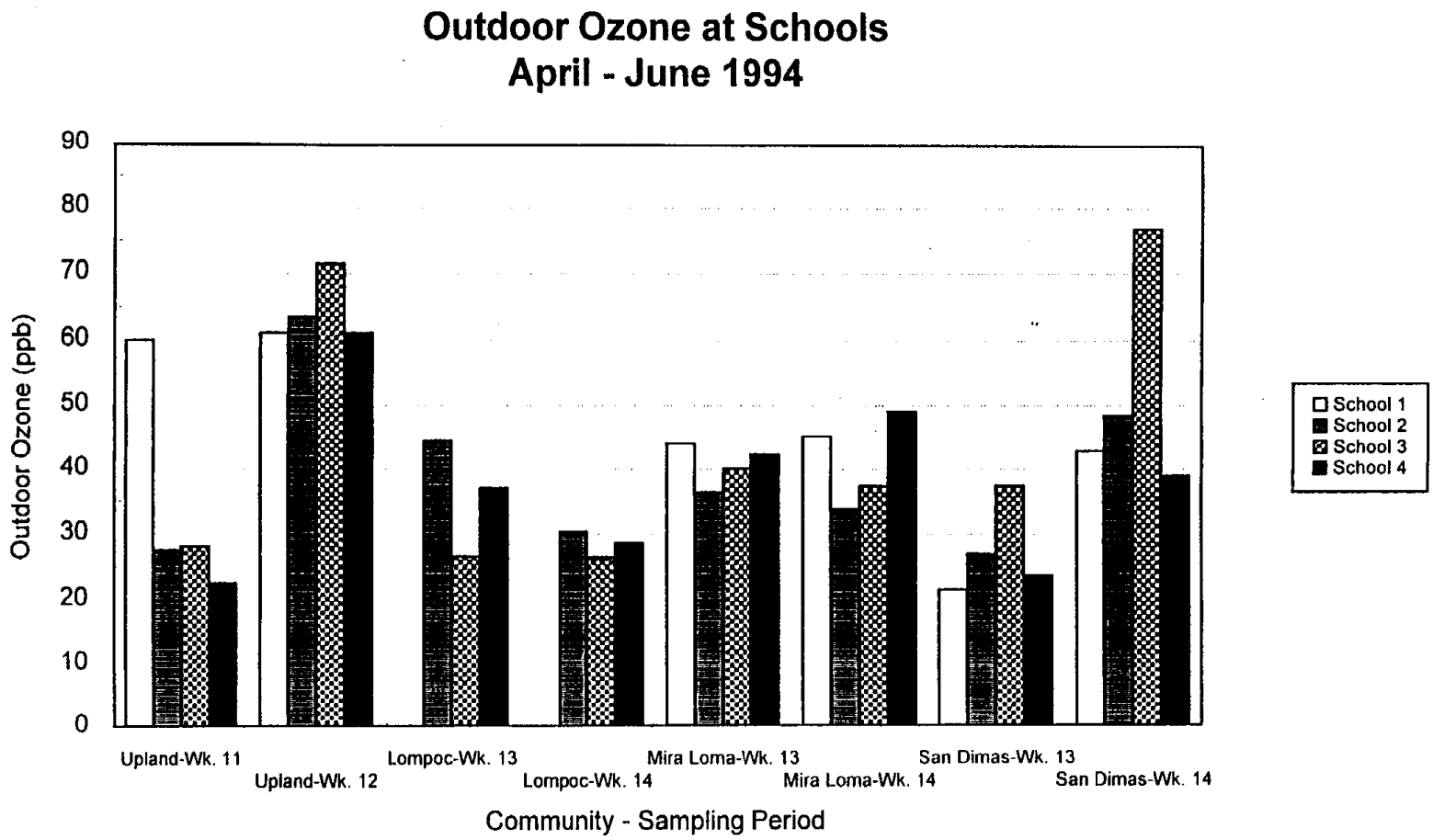


Figure 3-57. Comparison of the 8:00 a.m. to 3:00 p.m. integrated ozone concentrations outdoors at selected schools in the Spring.

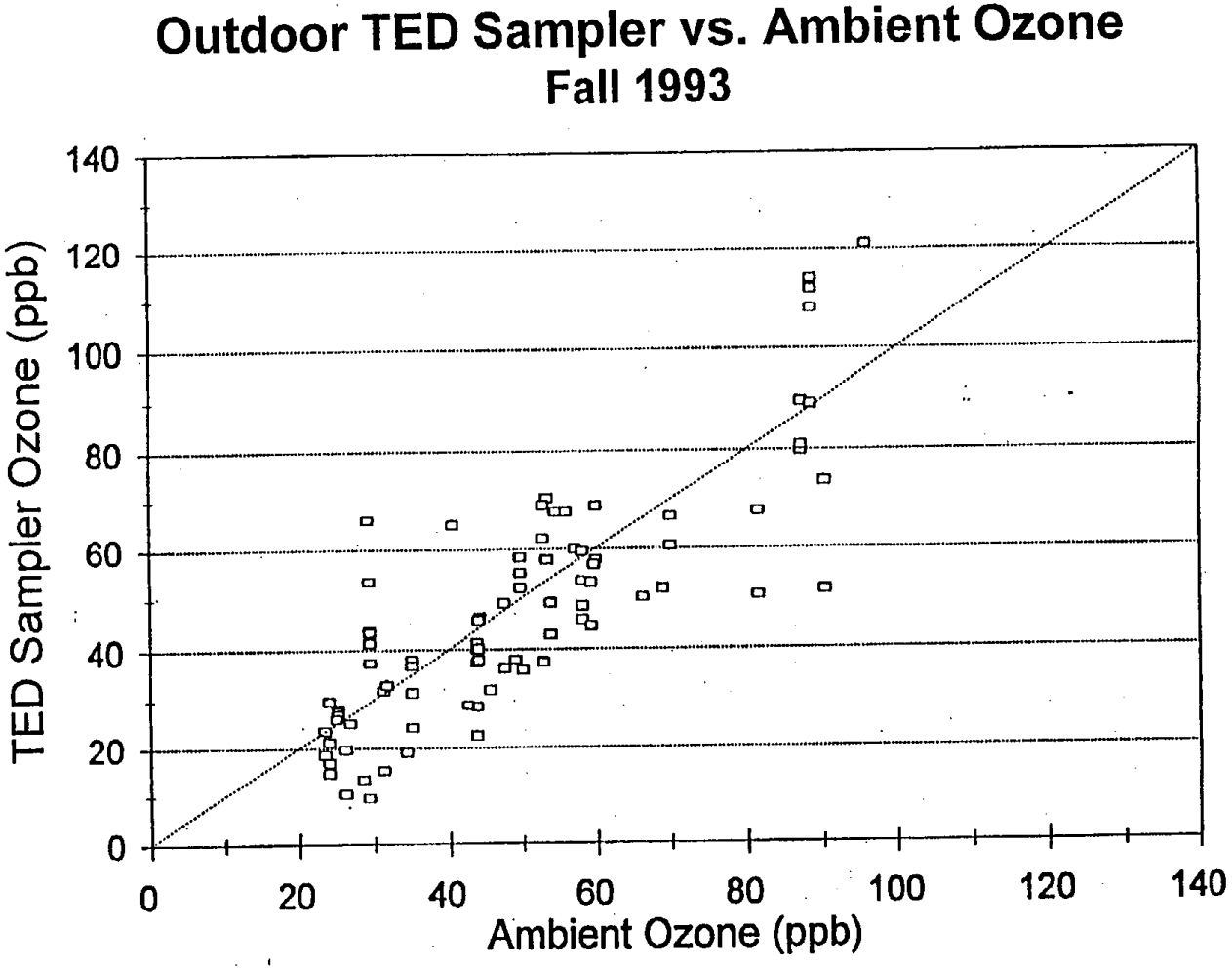


Figure 3-58. Comparison of 8:00 a.m. to 3:00 p.m. integrated ozone concentrations measured outdoors at all schools using the TED samplers to the values measured by the community monitors in the Fall.

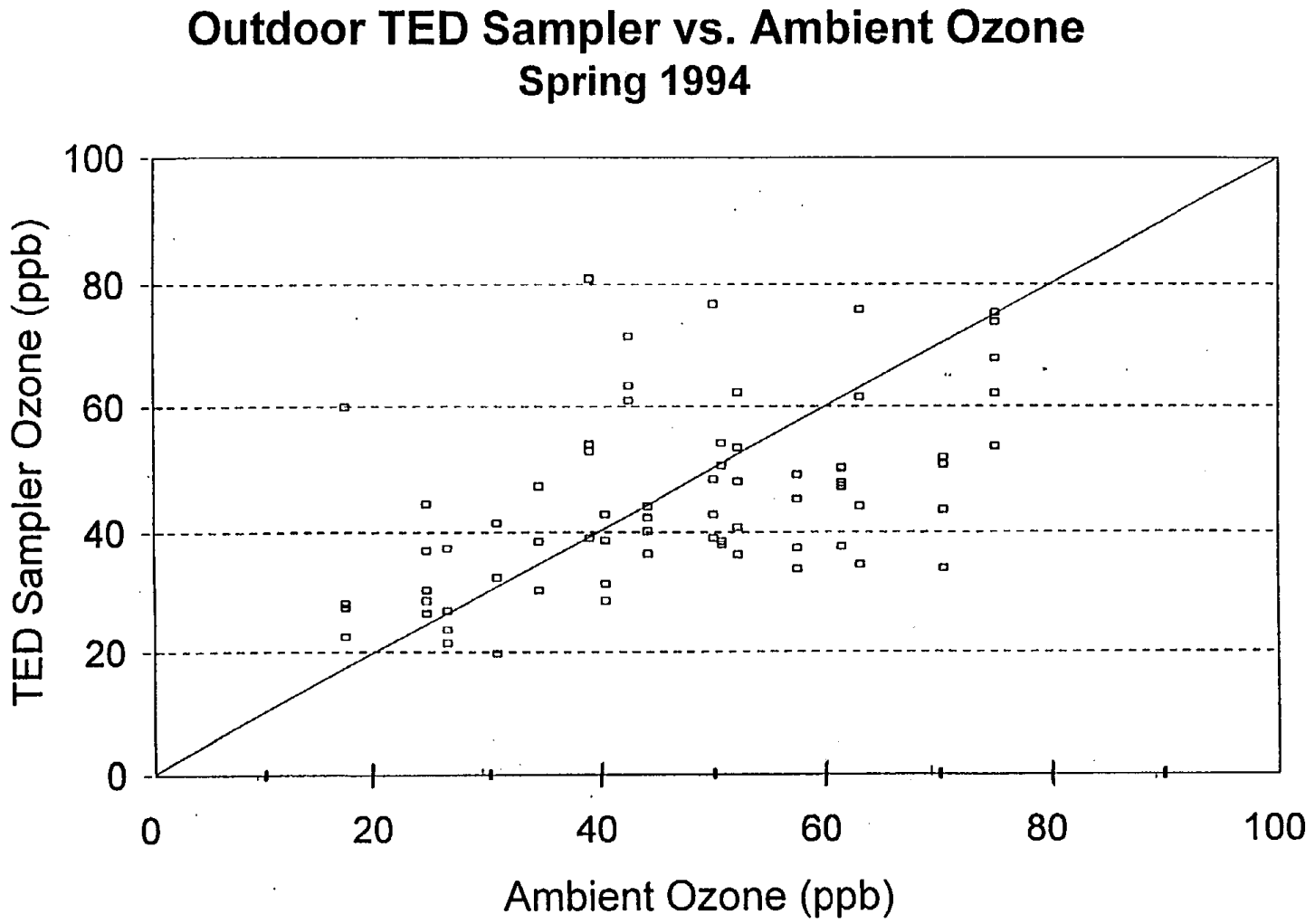


Figure 3-59. Comparison of 8:00 a.m. to 3:00 p.m. integrated ozone concentrations measured outdoors at schools using the TED samplers to the values measured by the community monitors in the Spring.

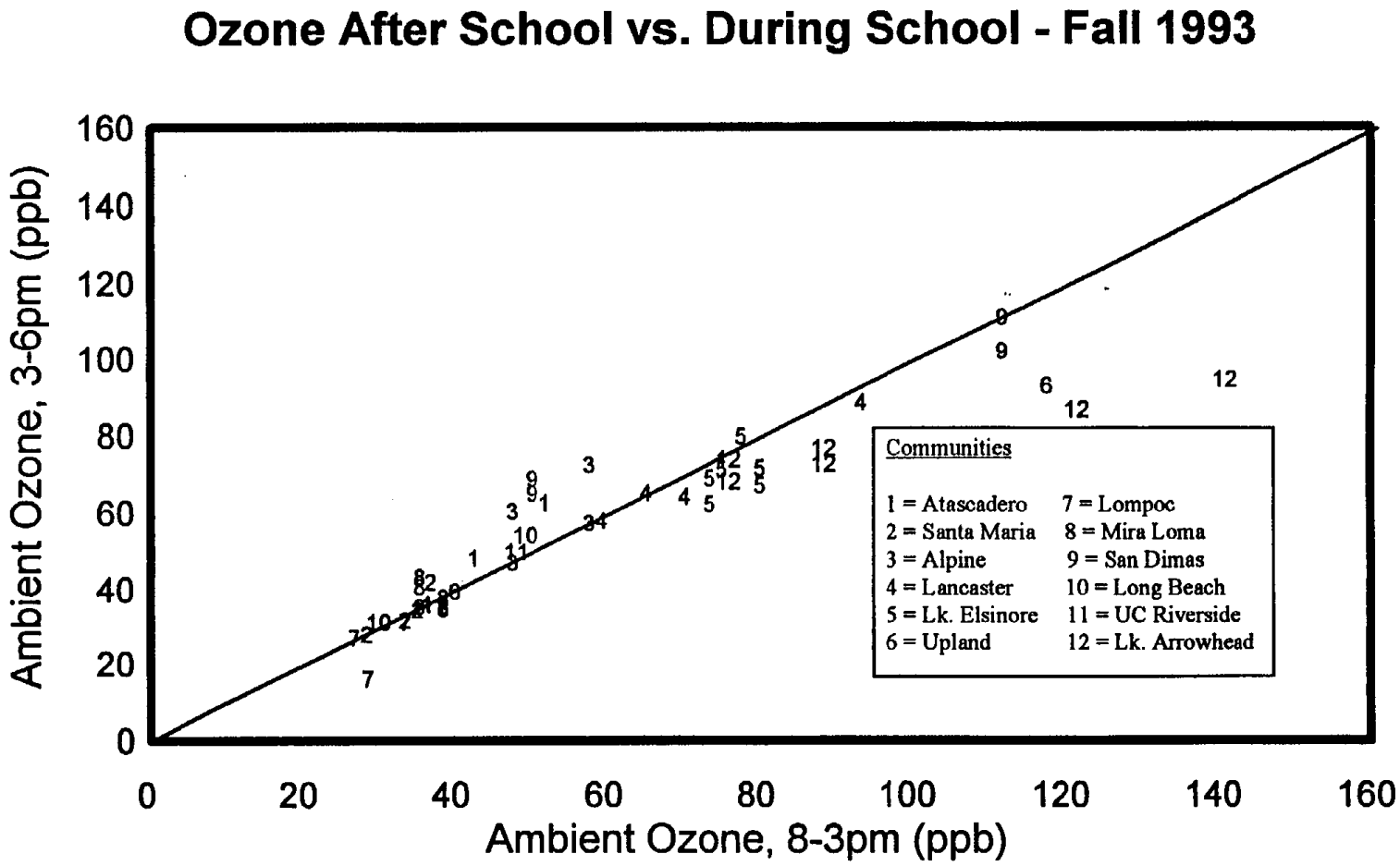


Figure 3-60. Comparion of the 8:00 a.m. to 3:00 p.m. and 3:00 to 6:00 p.m. integrated ozone concentrations measured by the community monitors in the Fall.

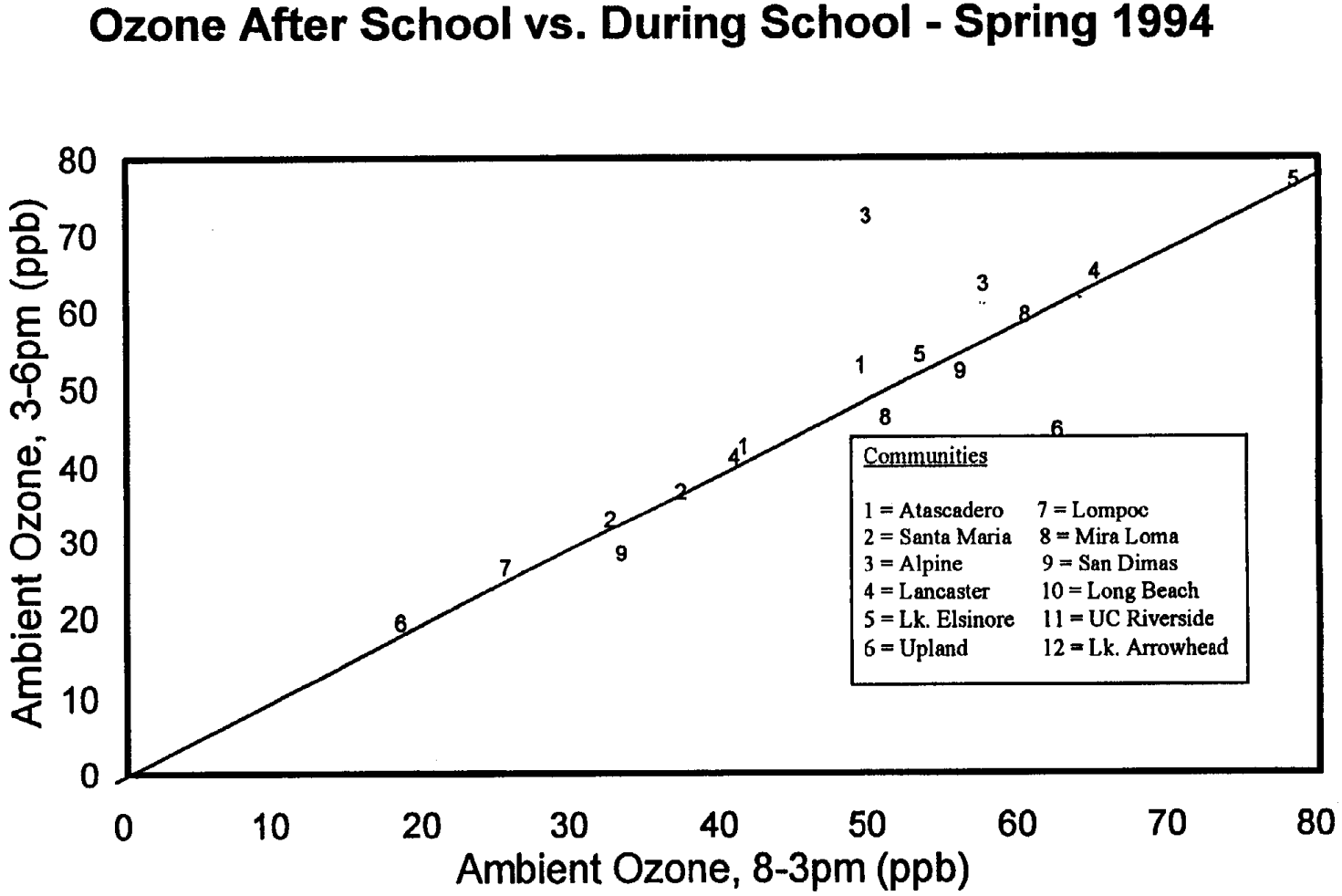


Figure 3-61. Comparion of the 8:00 a.m. to 3:00 p.m. and 3:00 to 6:00 p.m. integrated ozone concentrations measured by the community monitors in the Spring.

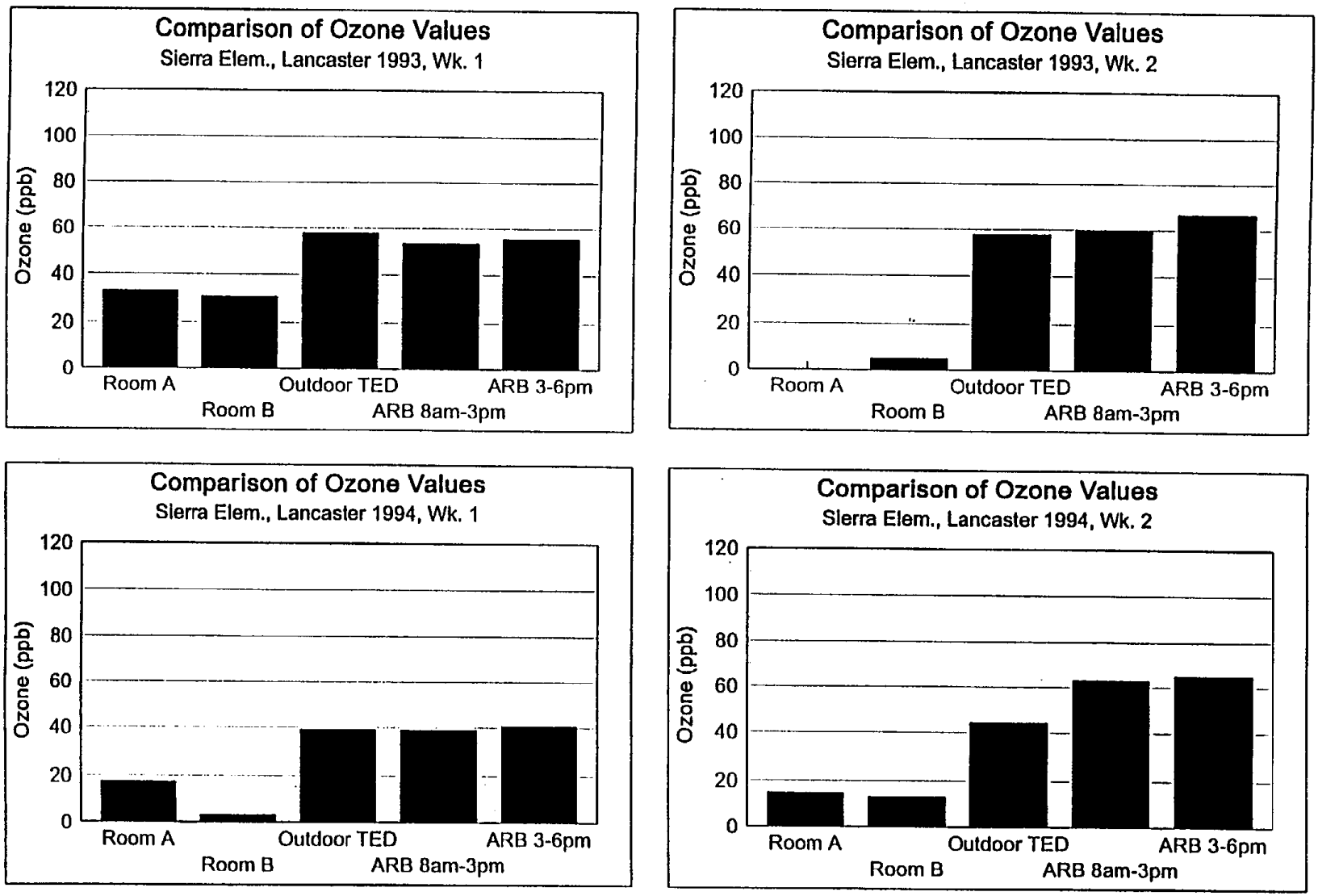


Figure 3-62. Comparison of 8:00 a.m. to 3:00 p.m. indoor ozone in schools, 8:00 a.m. to 3:00 p.m. outdoor ozone measured by the TED sampler and the community monitors, and 3:00 p.m. to 6:00 p.m. outdoor ozone measured by the community monitor at Atascadero.

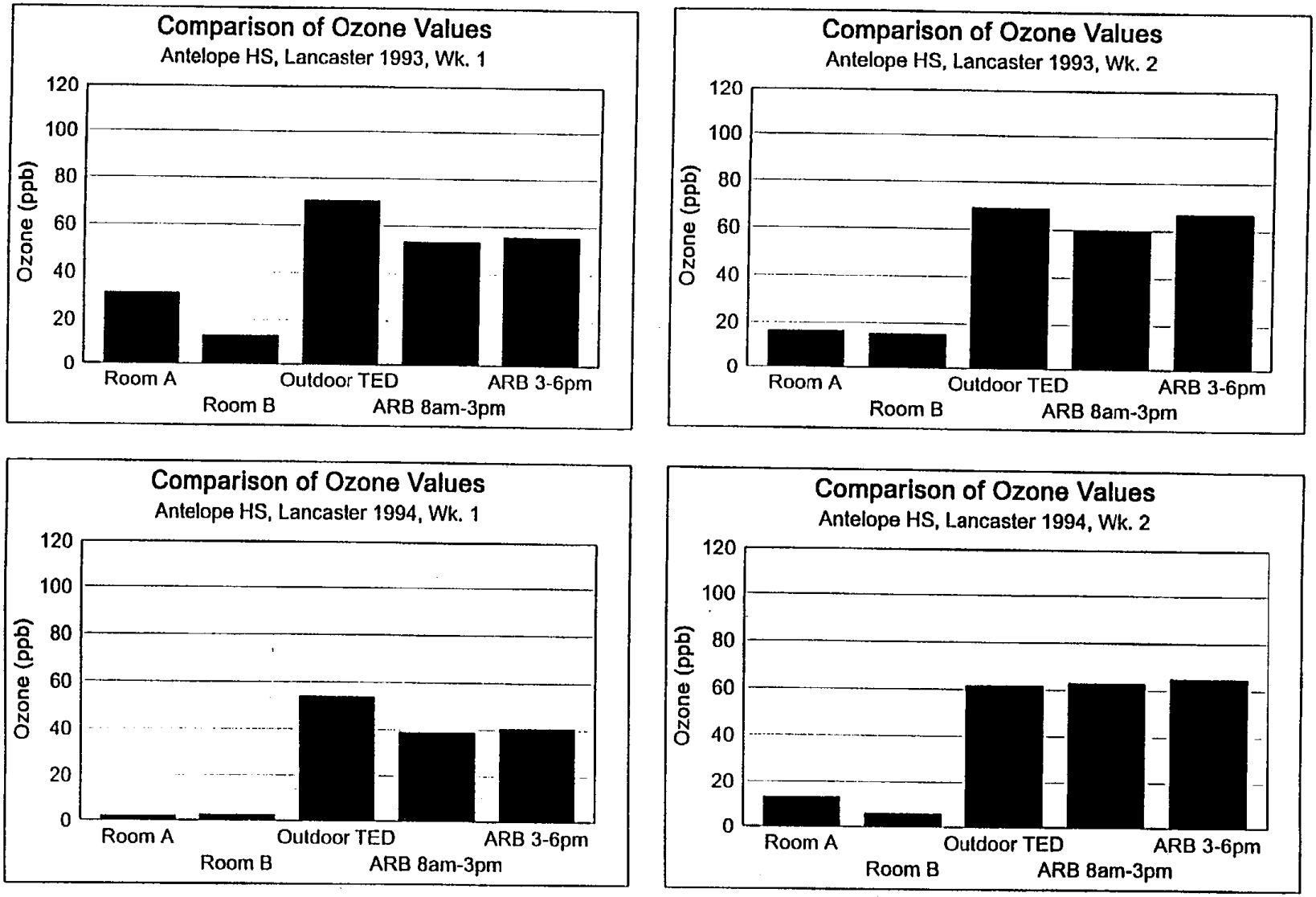


Figure 3-63. Comparison of 8:00 a.m. to 3:00 p.m. indoor ozone in schools, 8:00 a.m. to 3:00 p.m. outdoor ozone measured by the TED sampler and the community monitors, and 3:00 p.m. to 6:00 p.m. outdoor ozone measured by the community monitor at Atascadero.

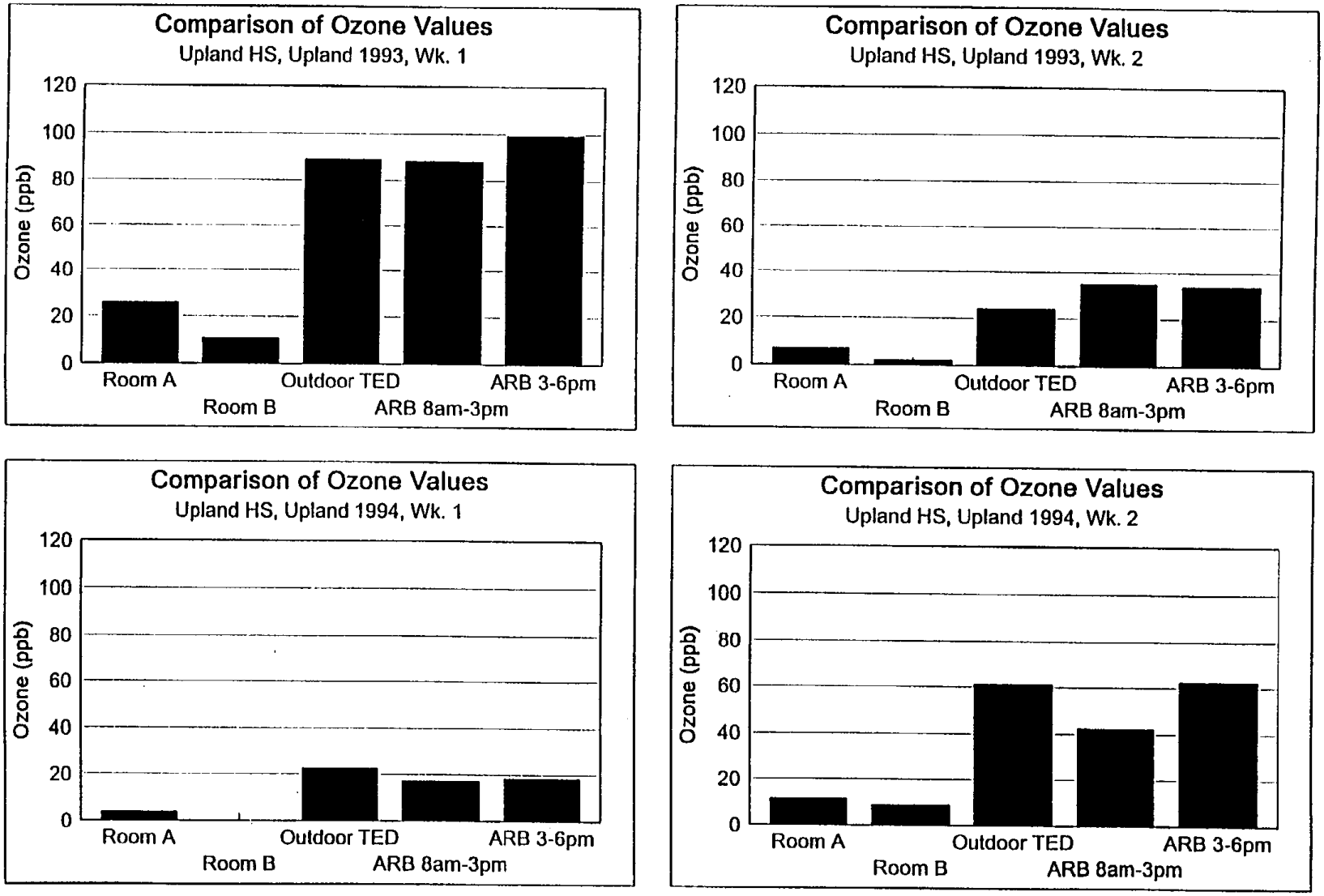


Figure 3-64. Comparison of 8:00 a.m. to 3:00 p.m. indoor ozone in schools, 8:00 a.m. to 3:00 p.m. outdoor ozone measured by the TED sampler and the community monitors, and 3:00 p.m. to 6:00 p.m. outdoor ozone measured by the community monitor at Upland.

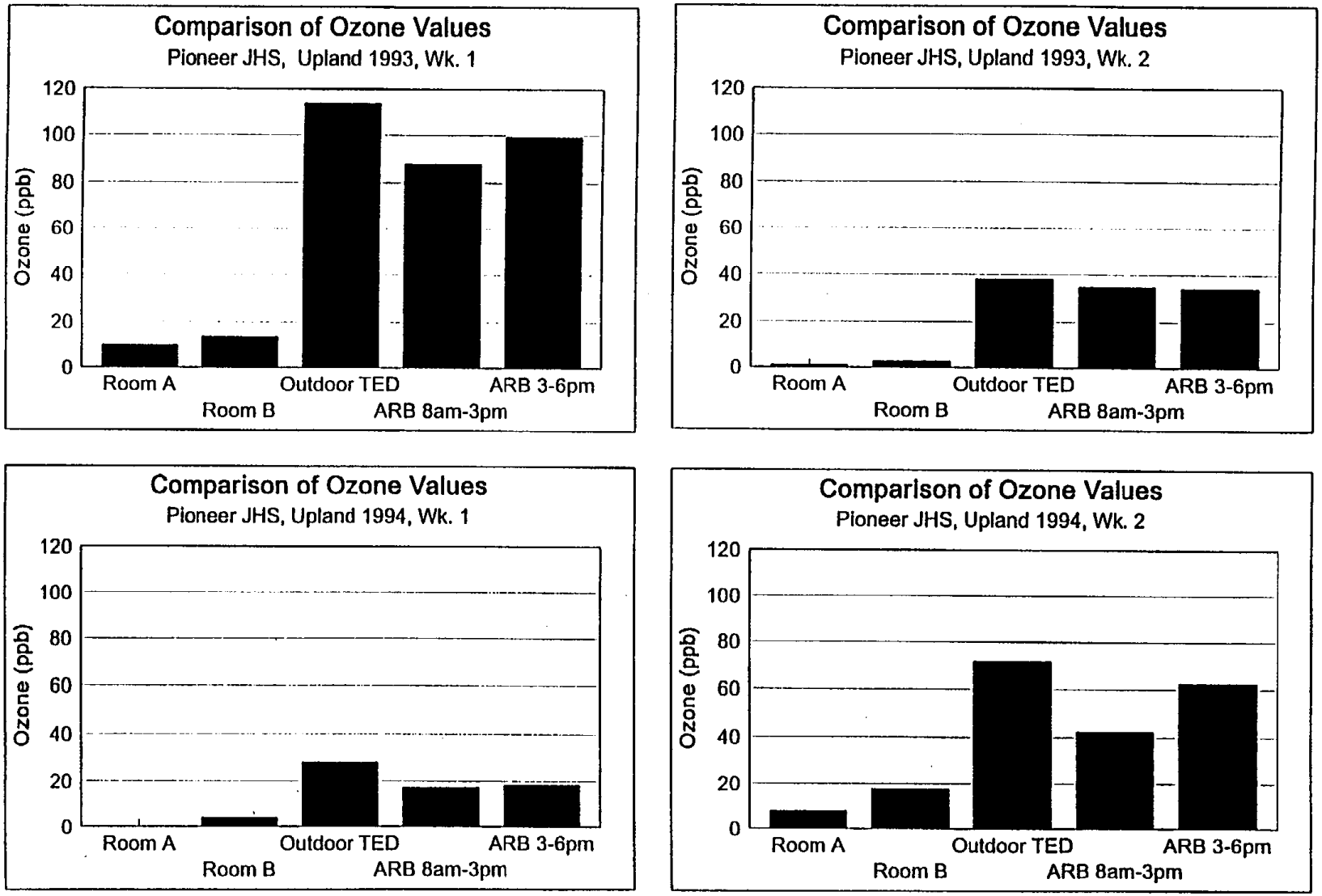


Figure 3-65. Comparison of 8:00 a.m. to 3:00 p.m. indoor ozone in schools, 8:00 a.m. to 3:00 p.m. outdoor ozone measured by the TED sampler and the community monitors, and 3:00 p.m. to 6:00 p.m. outdoor ozone measured by the community monitor at Upland.

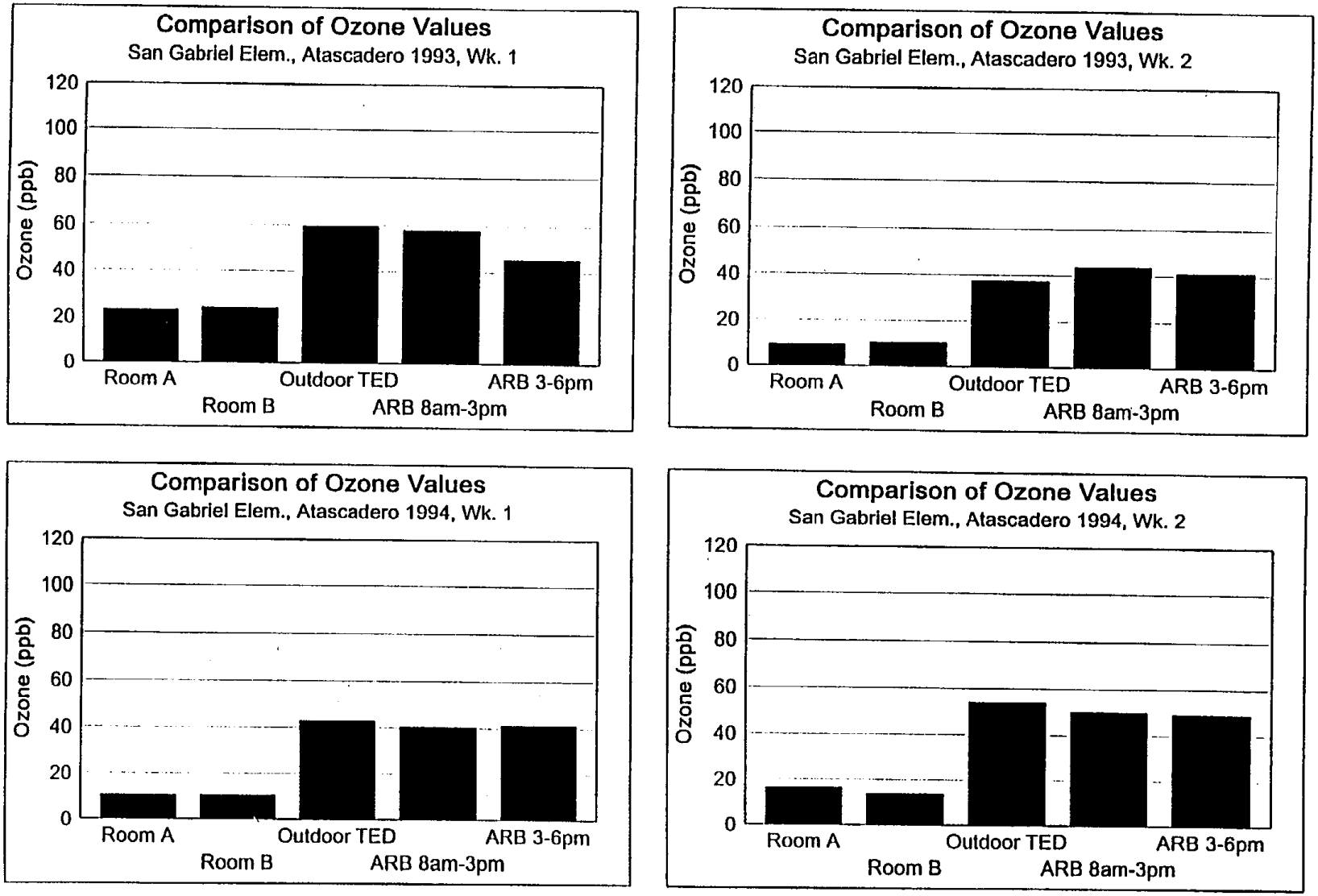
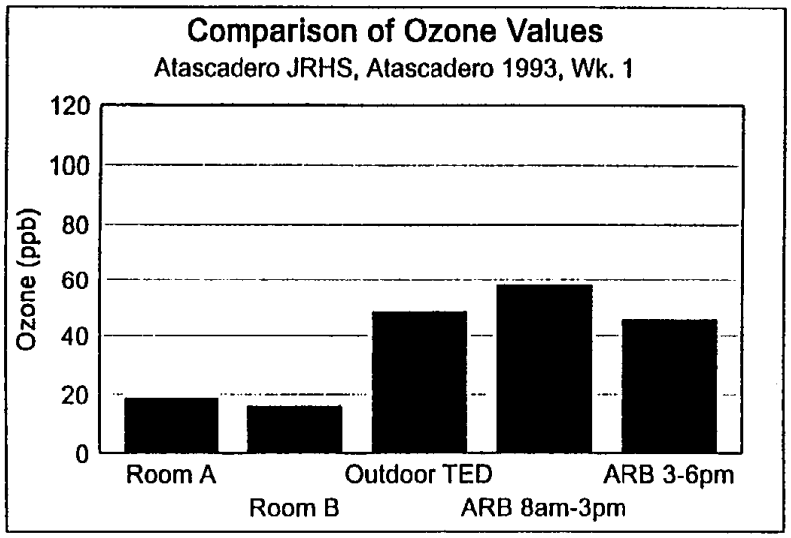
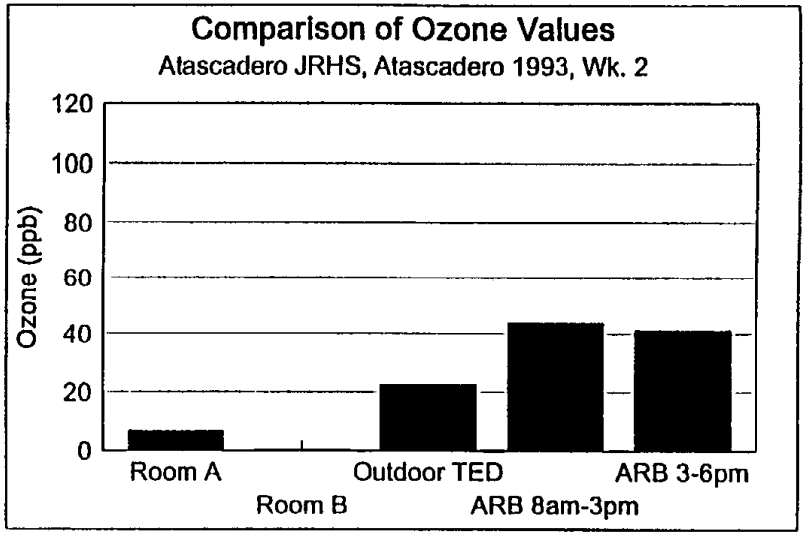
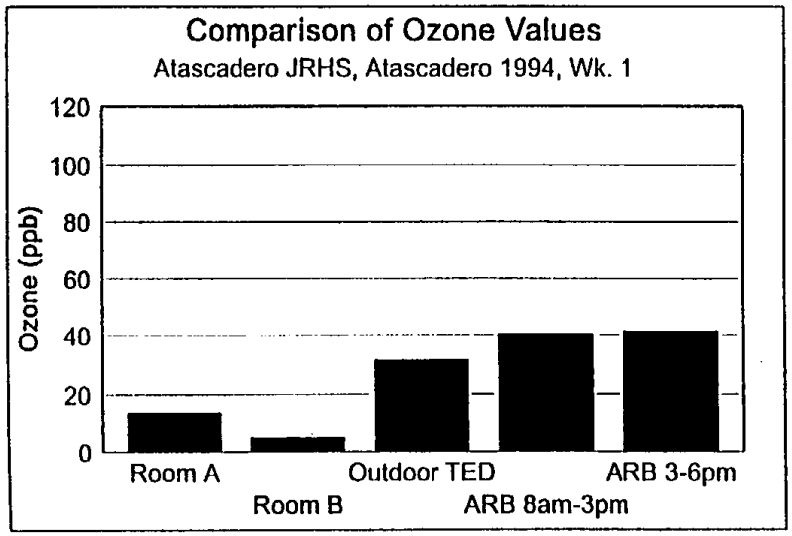


Figure 3-66. Comparison of 8:00 a.m. to 3:00 p.m. indoor ozone in schools, 8:00 a.m. to 3:00 p.m. outdoor ozone measured by the TED sampler and the community monitors, and 3:00 p.m. to 6:00 p.m. outdoor ozone measured by the community monitor at Lancaster.







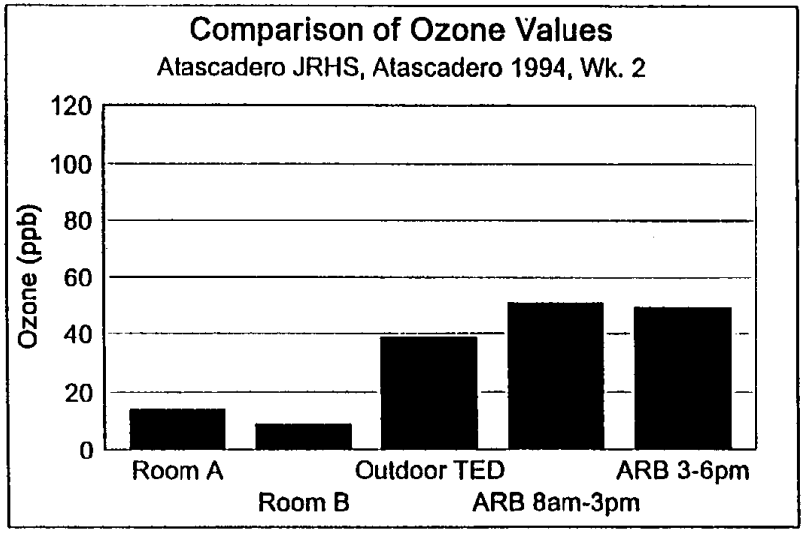


Figure 3-67. Comparison of 8:00 a.m. to 3:00 p.m. indoor ozone in schools, 8:00 a.m. to 3:00 p.m. outdoor ozone measured by the TED sampler and the community monitors, and 3:00 p.m. to 6:00 p.m. outdoor ozone measured by the community monitor at Lancaster.

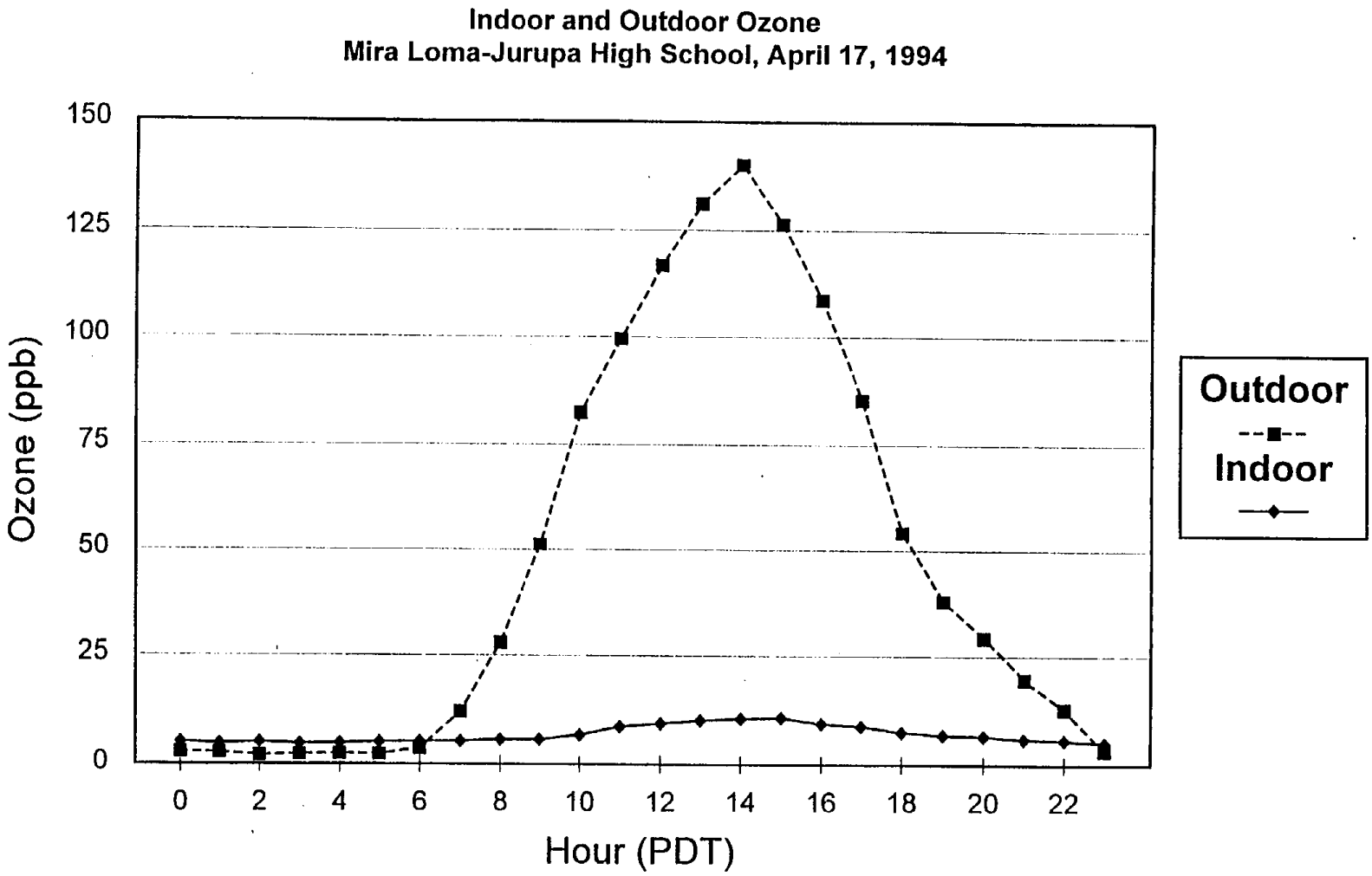


Figure 3-68. Hourly indoor and outdoor ozone in Room BF of Juruapa Valley High School in Mira Loma on April 17, 1994.

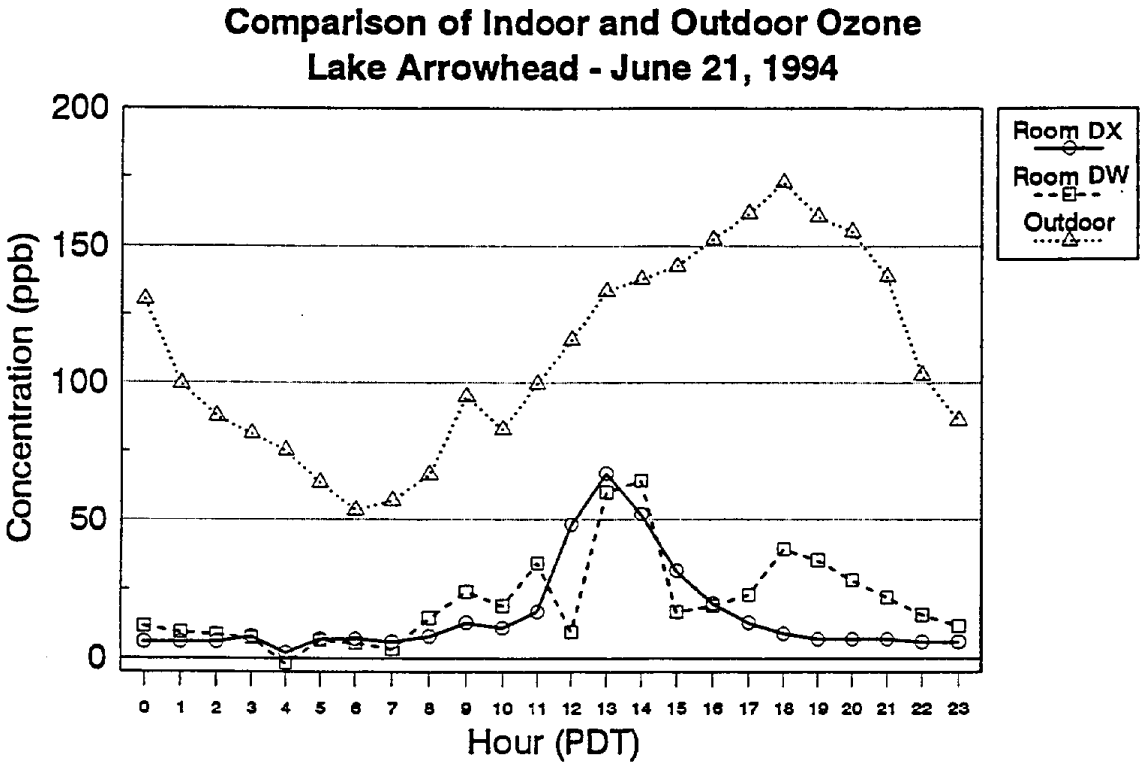


Figure 3-69. Comparison of hourly indoor and outdoor ozone concentrations on June 21, 1994 in Rooms DX and DW of Rim of the World High School in Lake Arrowhead.

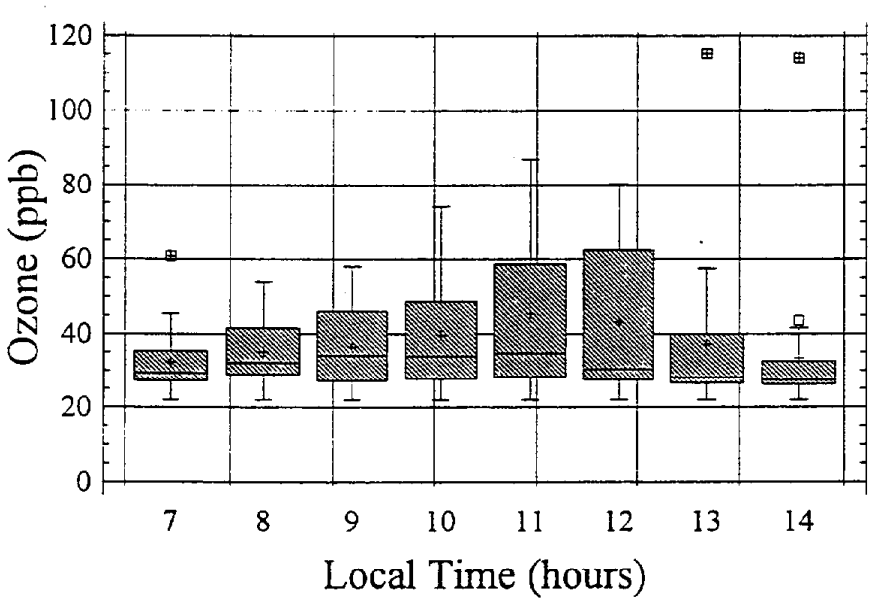


Figure 3-70. Hourly variations in indoor ozone in a classroom in Lake Arrowhead.

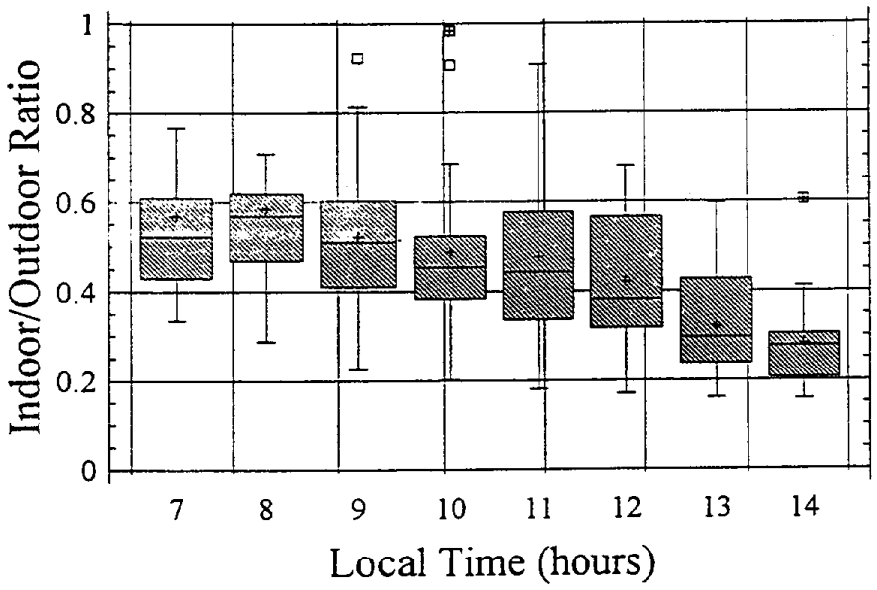


Figure 3-71. Hourly variations in indoor/outdoor ozone ratios in a classroom in Lake Arrowhead.

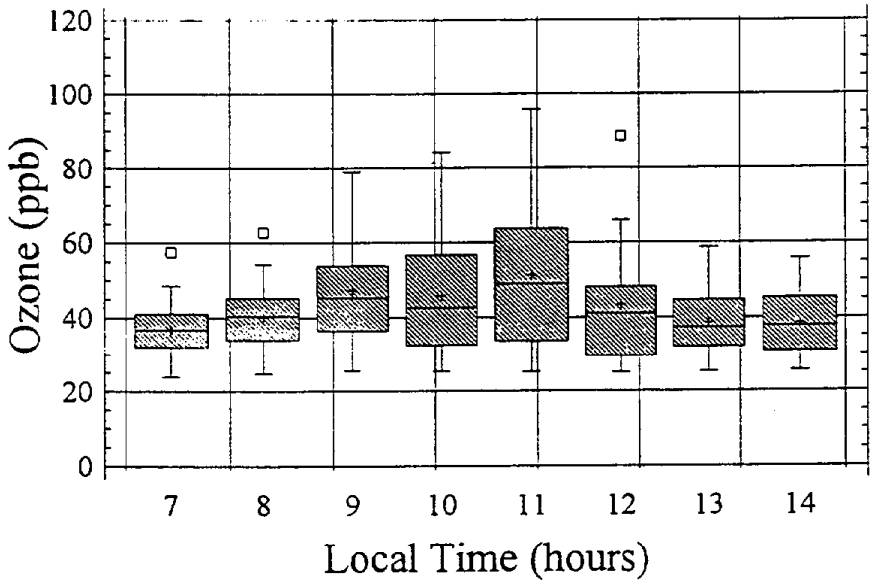


Figure 3-72. Hourly variations in indoor ozone in a classroom in Lake Arrowhead.

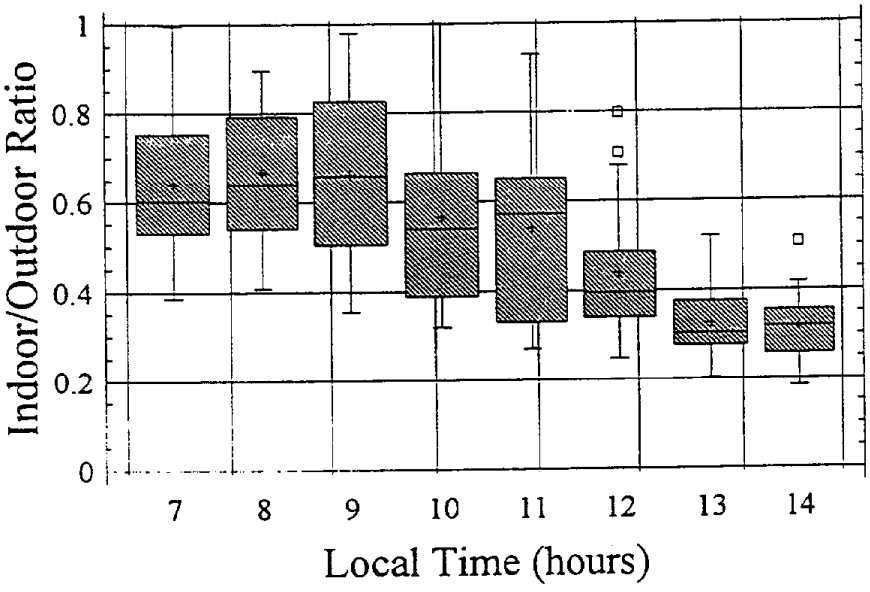


Figure 3-73. Hourly variations in indoor/outdoor ozone ratios in a classroom in Lake Arrowhead.

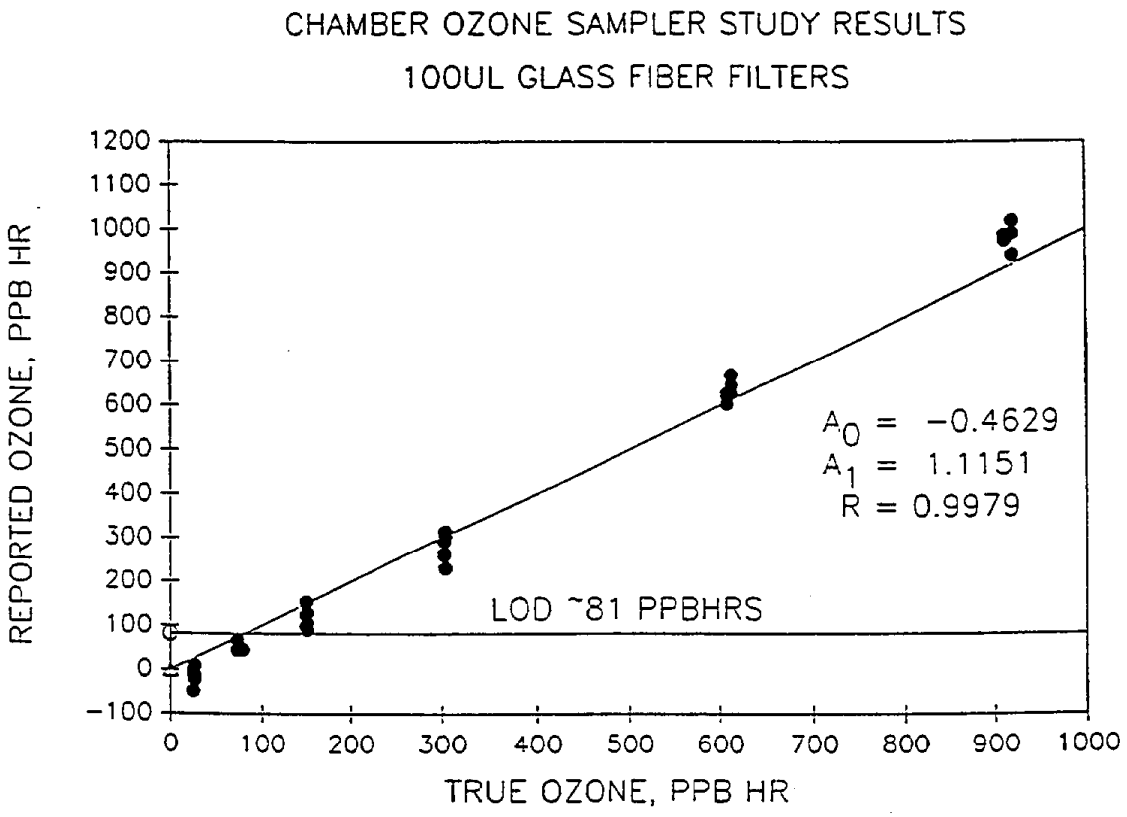


Figure 3-74. Chamber Ozone Sampler Study results: 100-μl glass-fiber filters.

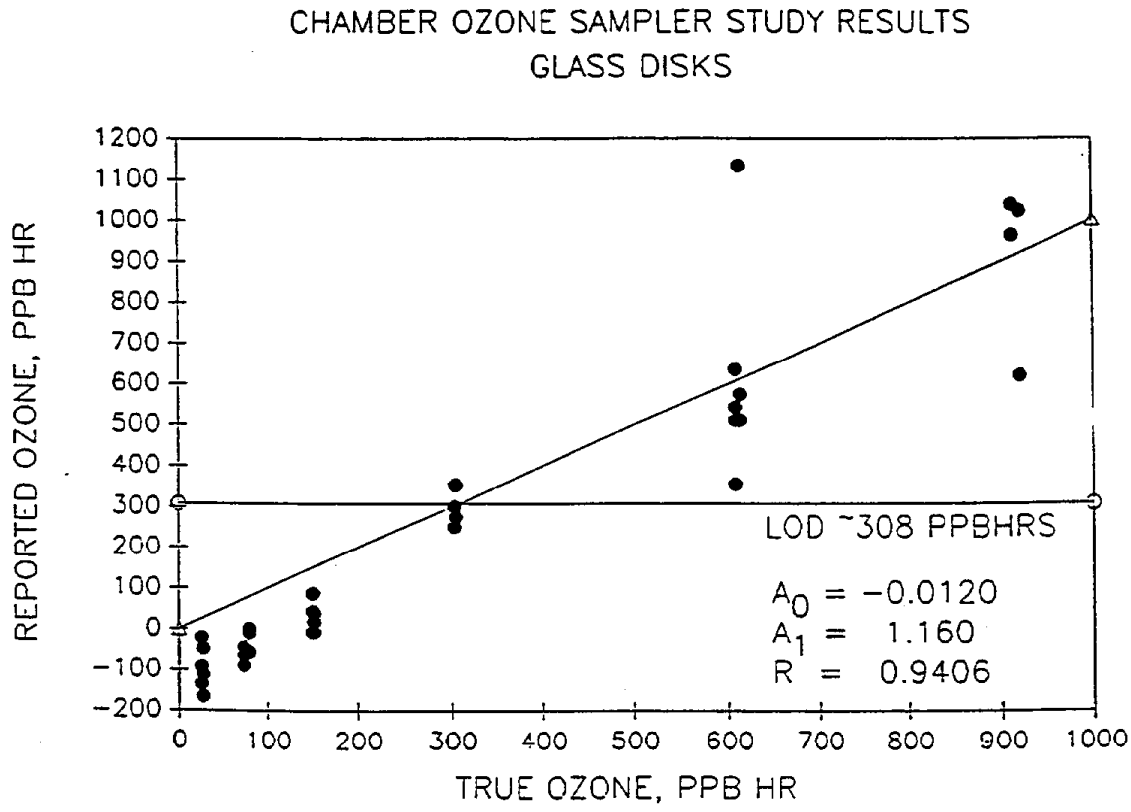


Figure 3-75. Chamber Ozone Sampler Study results: glass disks.

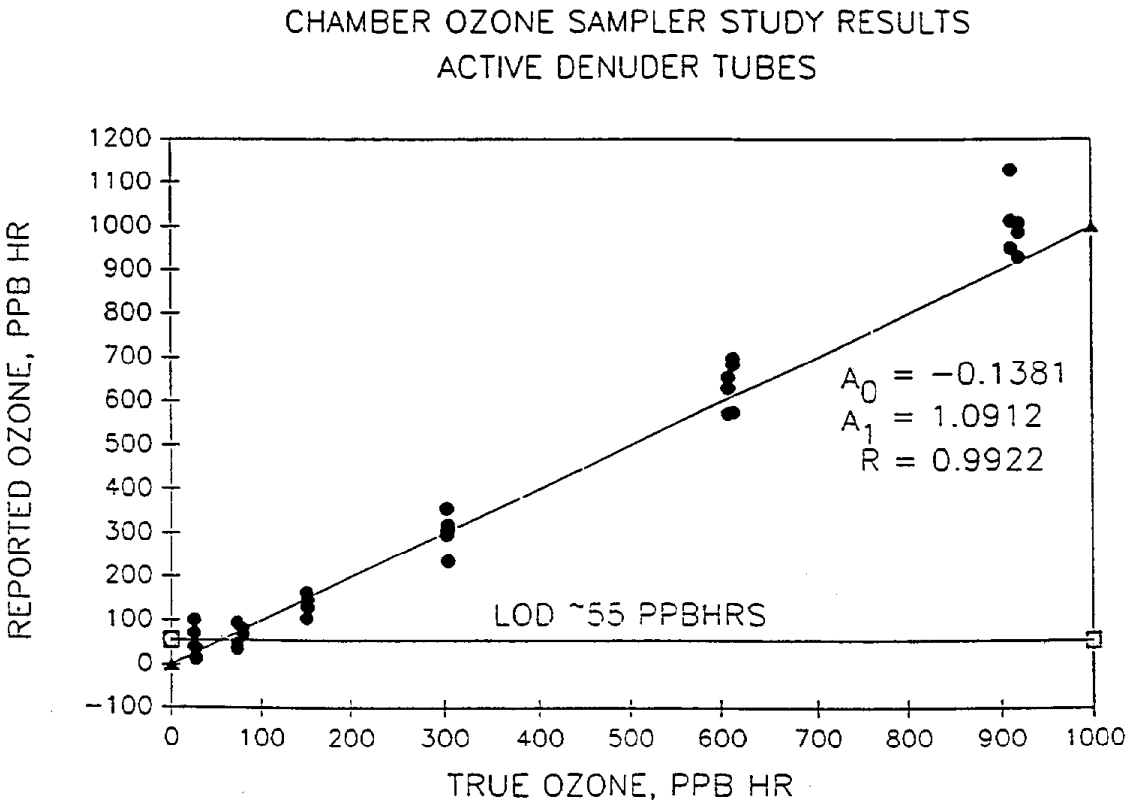


Figure 3-76. Chamber Ozone Sampler Study results: active denuder tubes.

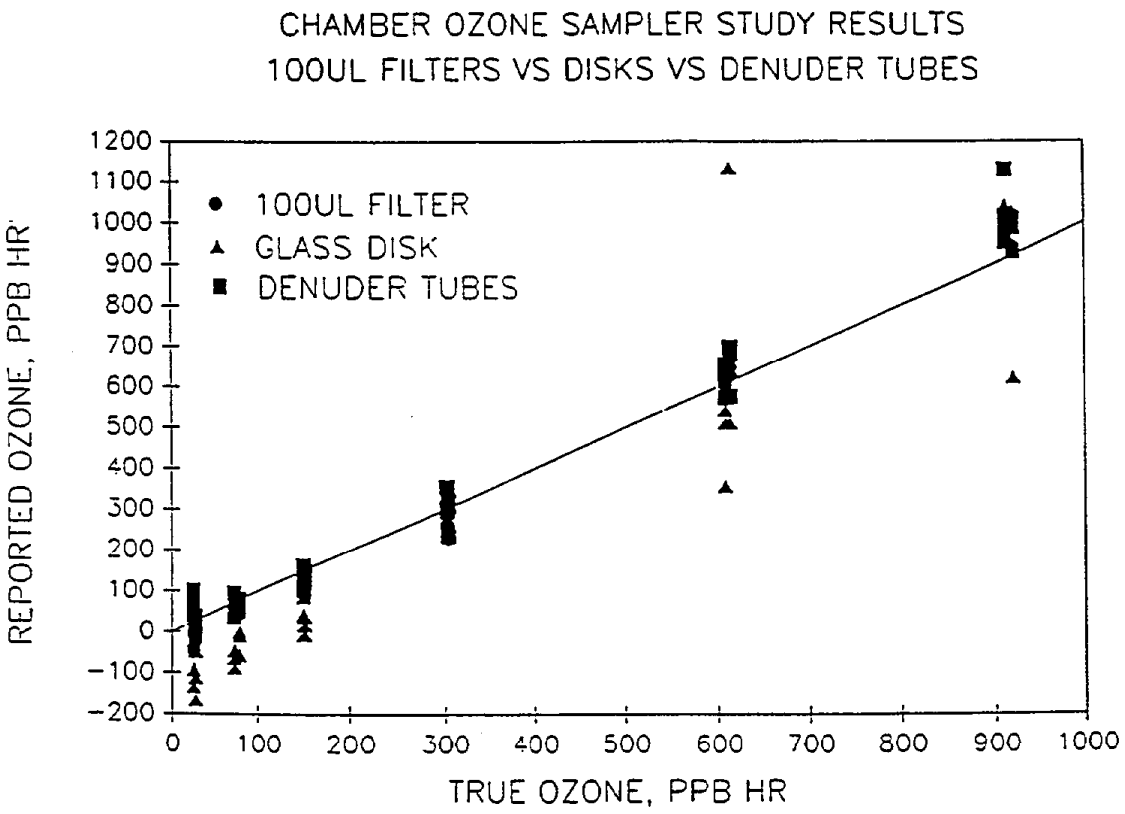


Figure 3-77. Chamber Ozone Sampler Study results: 100-μl filters versus disks versus denuder tubes.

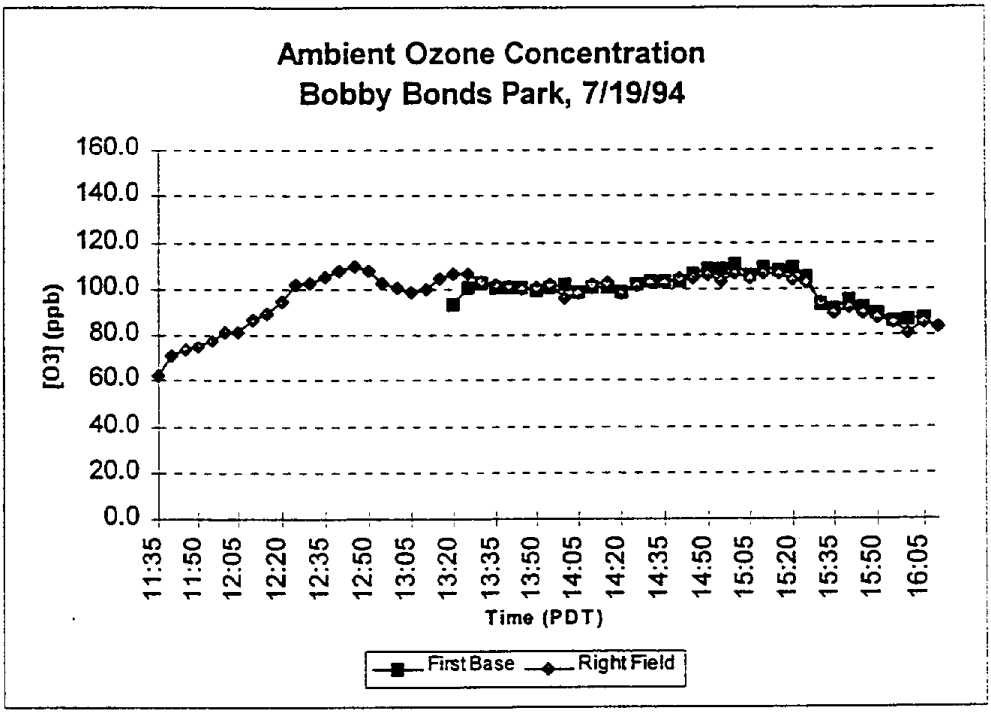
STi
Sonoma Technology, Inc.

Hour	15 min	Name of Child: / Counselor: / Pack #: / Observation:	L/M/H Activity	Name of Child: / Counselor: / Pack #: / Observation:	L/M/H Activity	Name of Child: / Counselor: / Pack #: / Observation:	L/M/H Activity	Name of Child: / Counselor: / Pack #: / Observation:	L/M/H Activity
12	15								
	30								
	45								
13	00								
	15								
	30								
	45								
14	00								
	15								
	30								
	45								
15	00								
	15								
	30								
	45								

Date: _____ Observer: _____ Location: Riverside - Bobby Bonds Park

Activity Log, Ver. 1.0: July 12, 1994
c:\epi\actlog2.cvs

Figure 3-78. Sample time-activity log used by observers.



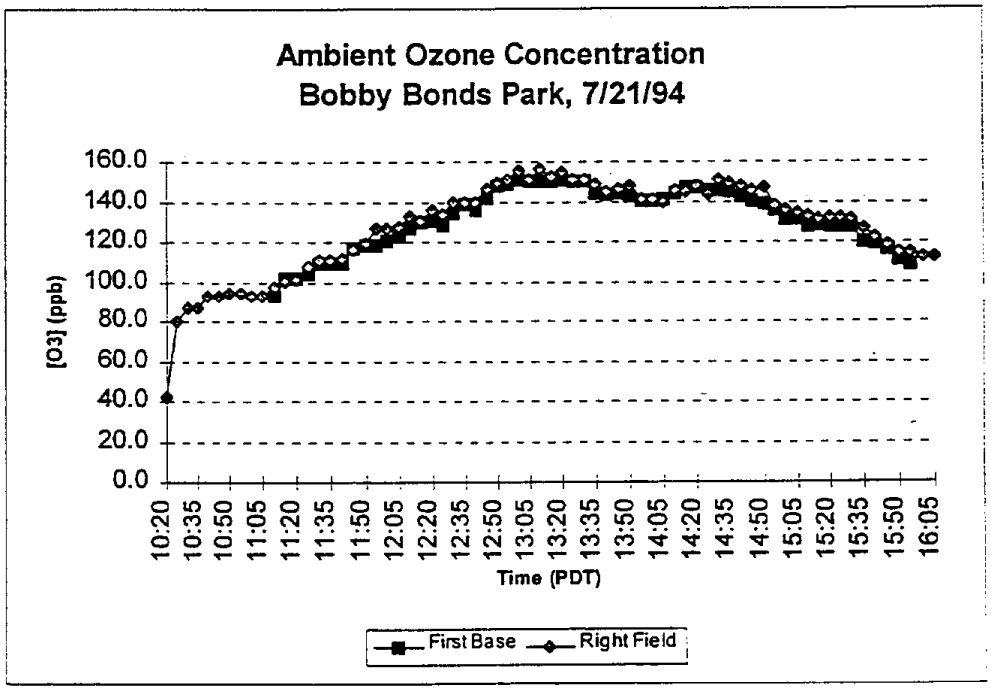
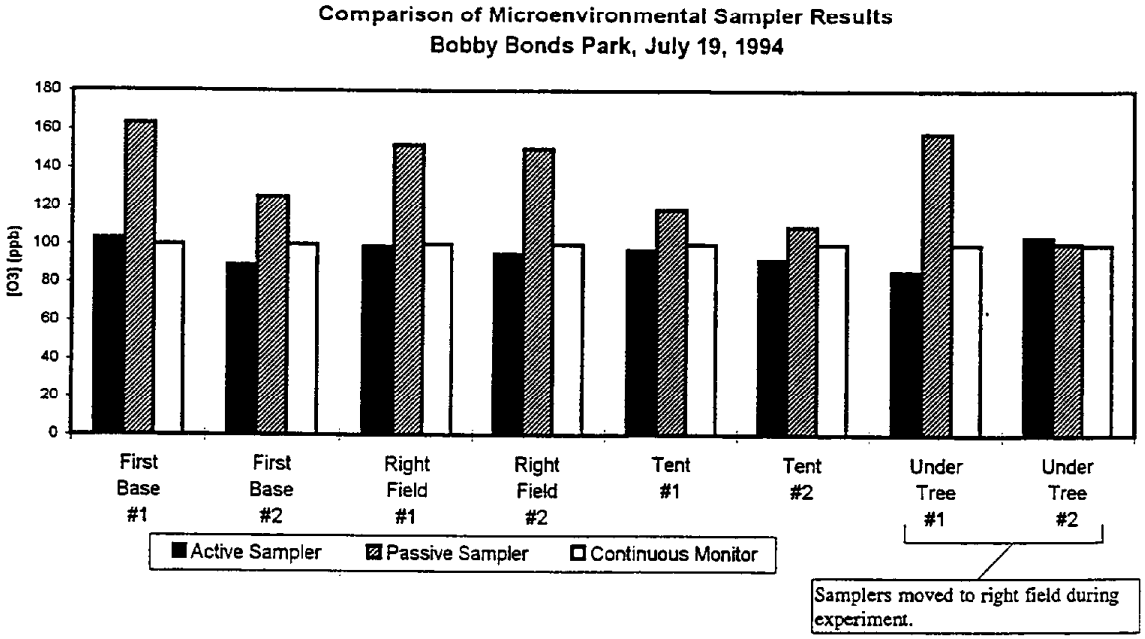


Figure 3-79. Ambient ozone concentrations at Bobby Bonds Park on July 19 and 21, 1994.



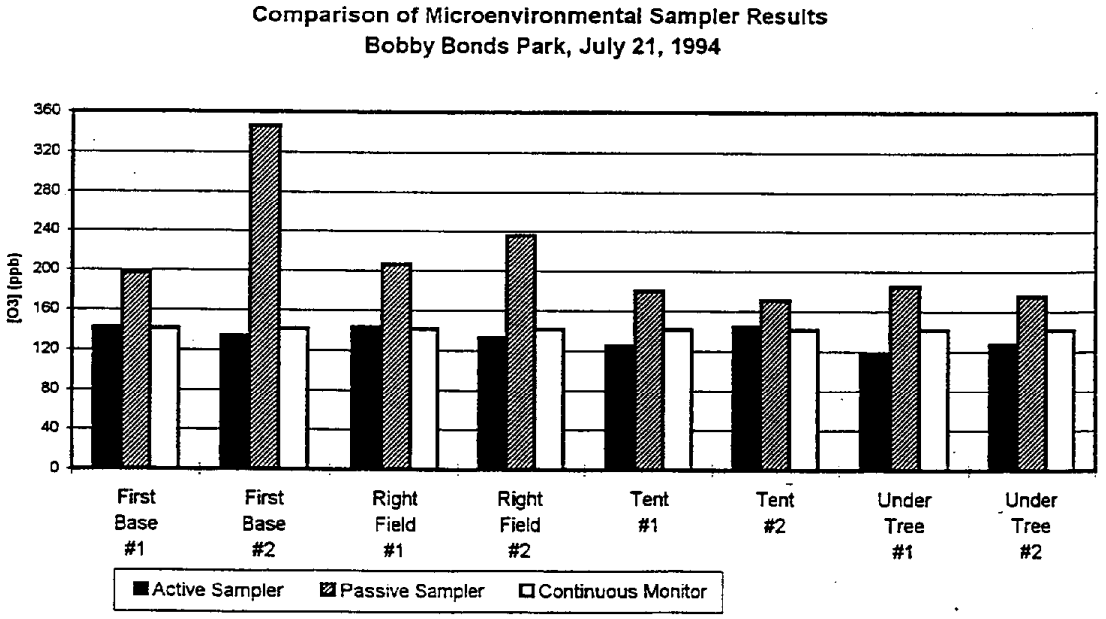


Figure 3-80. Comparison of active and passive microenvironmental ozone concentrations with ambient ozone concentrations at Bobby Bonds Park on July 19 and 21, 1994.

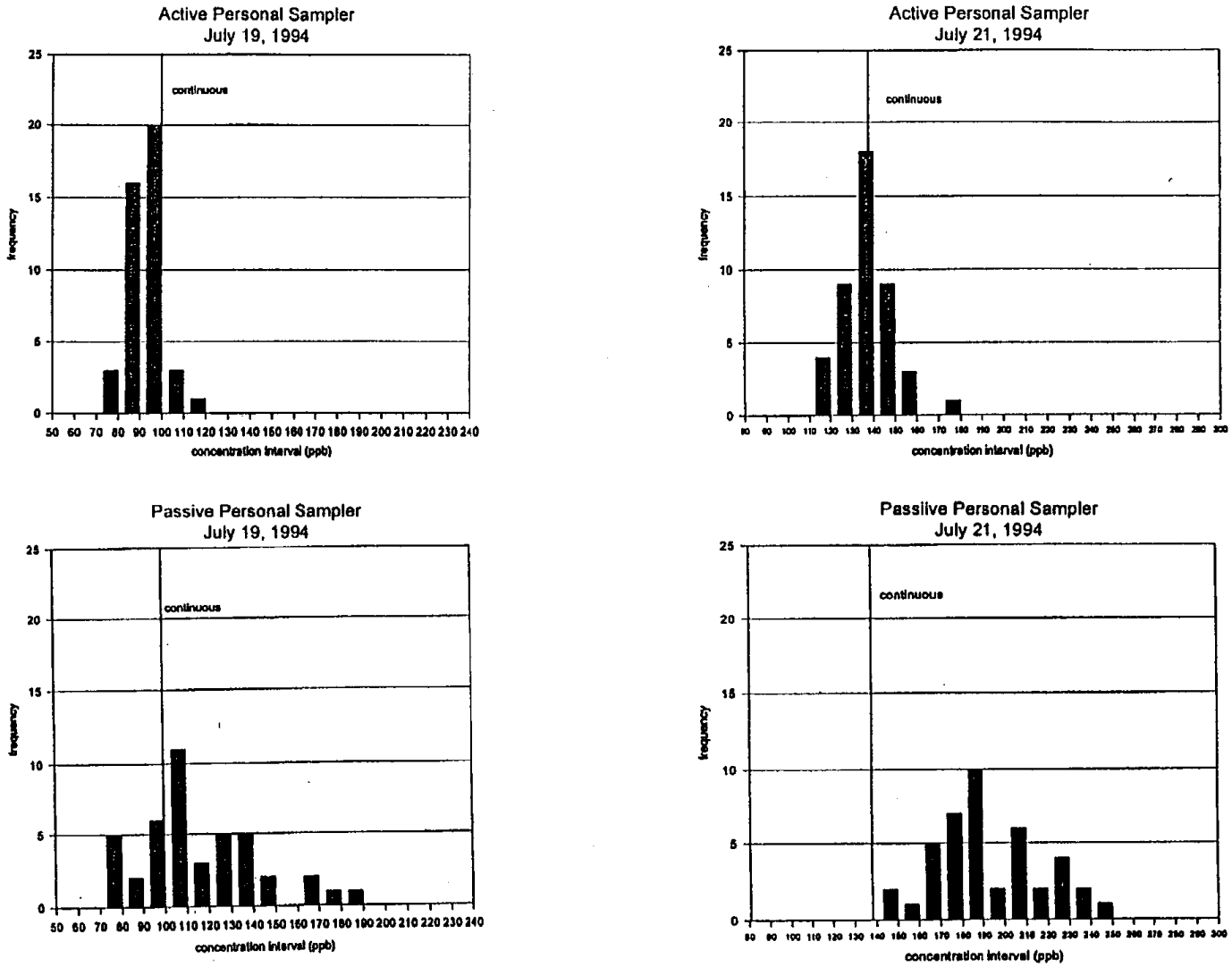


Figure 3-81. Frequency distributions of active and passive personal ozone concentrations at Bobby Bonds Park on July 19 and 21, 1994.

USC

ACTIVITY DIARY

ID:_____

Date:____/____/____

What time did you get up?

time: ___:___ am or pm

What time did you start filling this diary out?

time: ___:___ am or pm

What time did you go to bed?

time: ___:___ am or pm

INSTRUCTIONS

Each page covers an hour of your day. (An hour lasts 60 minutes). The first page is 7:00 to 7:59 a.m. and the last page is 8:00 to 8:59 p.m.. If you get up before 7:00 start filling the diary out when it is 7:00 to 7:59 a.m.. Try to fill out each page at the end of the hour. If you miss a few pages, fill them out as soon as you can. Stop filling out the pages when you go to bed or at 8:59 p.m., whichever comes first.

Please tell the truth. There are no right or wrong answers. We will not show your answers to anyone.

The first question on each page says ACTIVITIES (PUT MAIN ONE FIRST). Write down what you did during this time period. First put the what you did for the longest time during that hour and then list the other things that you did.

The second question says WHERE WERE YOU DURING THIS TIME?:

Pick from four choices- HOME, NEAR HOME, SCHOOL, OTHER. If you were in more than one place check all the places you were and put a circle around the one where you were longest.

HOME means the inside of your house, your yard, garage, driveway and the street or sidewalk in front of your house.

NEAR HOME means your neighborhood -- places close to your house such as friend's houses, stores, playgrounds, swimming pools, sports fields, your church and so on.

SCHOOL means your school -- the school building, outside on the school grounds where you have recess or lunch, the school playing fields, courts or playground and the sidewalk next to school.

OTHER means all places outside your community. If you have to drive in a car or ride a bus more than 10 to 15 minutes you are probably outside your community. For example, you might go to shopping malls, restaurants, relatives' homes, or a special park.

The third question on each page says AMOUNT OF TIME OUTDOORS. How much of this hour did you spend outdoors? Do not include time you spend riding in a motor vehicle (such as a car, bus, truck, van, motorcycle) as time outdoors. There are four choices for the amount of time outdoors. Choose one:

NONE means no time outdoors

SOME means less than 30 minutes outdoors. (30 minutes is half the hour)

MOST means more than 30 minutes, but not the whole hour.

ALL means you were outdoors for the entire hour.

The fourth question on each page is AMOUNT OF TIME IN TRAVEL (CAR,BUS,VAN,TRUCK,TRAIN OR MOTORCYCLE). Do not include bicycling, skateboarding, skating rollerblading, walking or running as TRAVEL -- they are OUTDOOR time. Pick one of the four choices:

NONE means you did not travel during this period.

SOME means you travelled and it took less than 30 minutes.

MOST means that you travelled for more than 30 minutes but not the whole hour.

ALL means you were travelling for the entire hour.

Figure 3-82. Time-activity diary used for the personal ozone pilot study.

Page 1 of 2

The fifth question on each page says AMOUNT OF TIME VERY PHYSICALLY ACTIVE. Very physically active means doing things that get your body moving and use a lot of energy and make you breathe hard. Some examples are soccer, basketball, volleyball, tennis, bicycling, walking fast, hiking, running, jogging, skateboarding, rollerblading, skating, swimming, aerobics, dancing, dodgeball, four square, kickball, tag, hopscotch, jumping rope, frisbee, skiing and so on.

Tell us how much of this hour you were VERY PHYSICALLY ACTIVE. Pick one of four choices:

NONE of the time being very physically active

SOME of the time (less than 30 minutes)

MOST of the time (30 minutes or more)

ALL of the time being very physically active

8:00 a.m. to 8:59 a.m.

ACTIVITIES (PUT MAIN ONE FIRST):

Breakfast
Walked To school
In class - 8:35 on

SAMPLE

WHERE WERE YOU DURING THIS TIME?

✓home ✓near home (✓school) _other

AMOUNT OF TIME OUTDOORS:

_none ✓some _most _all

AMOUNT OF TIME IN TRAVEL (CAR,BUS,VAN TRUCK,TRAIN OR MOTORCYCLE):

✓none _some _most _all

AMOUNT OF TIME VERY PHYSICALLY ACTIVE:

✓none _some _most _all

12:00 p.m. to 12:59 p.m.

ACTIVITIES (PUT MAIN ONE FIRST):

Ate lunch
Played prisoner and basketball
Hung out with friends

SAMPLE

WHERE WERE YOU DURING THIS TIME?

_ home _near home ✓school _other

AMOUNT OF TIME OUTDOORS:

_none _some _most ✓all

AMOUNT OF TIME IN TRAVEL (CAR,BUS,VAN TRUCK,TRAIN OR MOTORCYCLE):

✓none _some _most _all

AMOUNT OF TIME VERY PHYSICALLY ACTIVE:

_none _some ✓most _all

3:00 p.m. to 3:59 p.m.

ACTIVITIES (PUT MAIN ONE FIRST):

Walked from school To friend's
Snack
Video Games
Played catch, tag

SAMPLE

WHERE WERE YOU DURING THIS TIME?

_ home (✓near home) ✓school _other

AMOUNT OF TIME OUTDOORS:

_none ✓some _most _all

AMOUNT OF TIME IN TRAVEL (CAR,BUS,VAN TRUCK,TRAIN OR MOTORCYCLE):

✓none _some _most _all

AMOUNT OF TIME VERY PHYSICALLY ACTIVE:

_none ✓some _most _all

BREATHING PROBLEMS:

✓wheeze _trouble breathing

MEDICATIONS YOU TOOK:

_puffer/inhaler _pill (or liquid)

Figure 3-82. Time-activity diary used for the personal ozone pilot study.

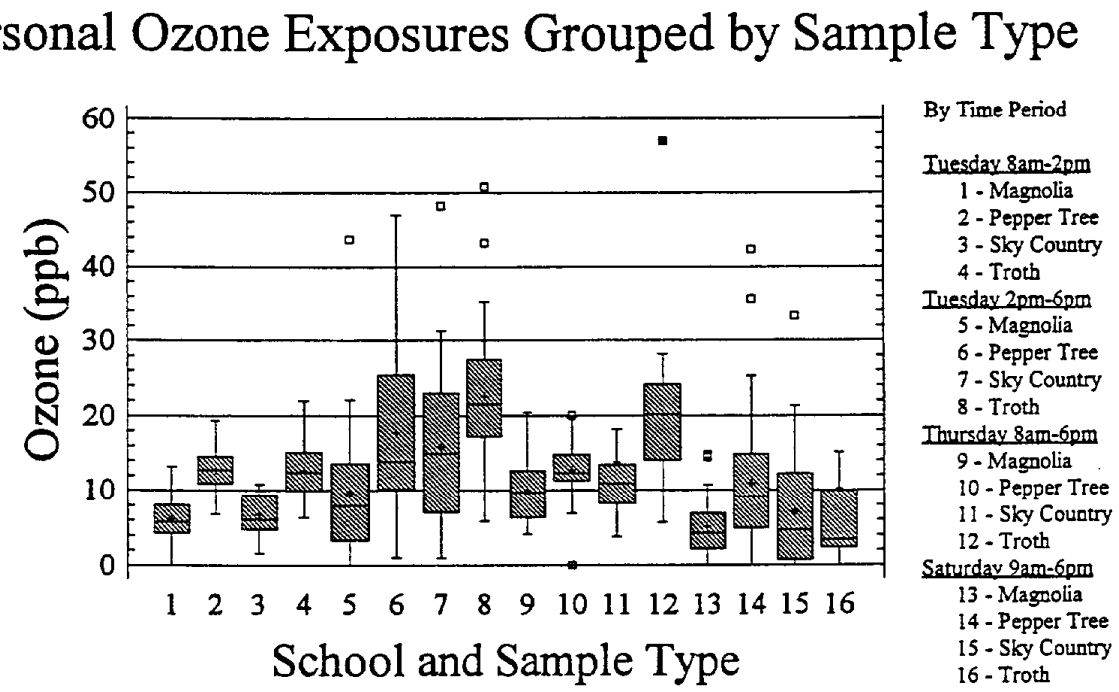


Figure 3-83. Personal ozone exposures for various schools and sample types, grouped by sample type.

Personal Ozone Exposures Grouped Chronologically

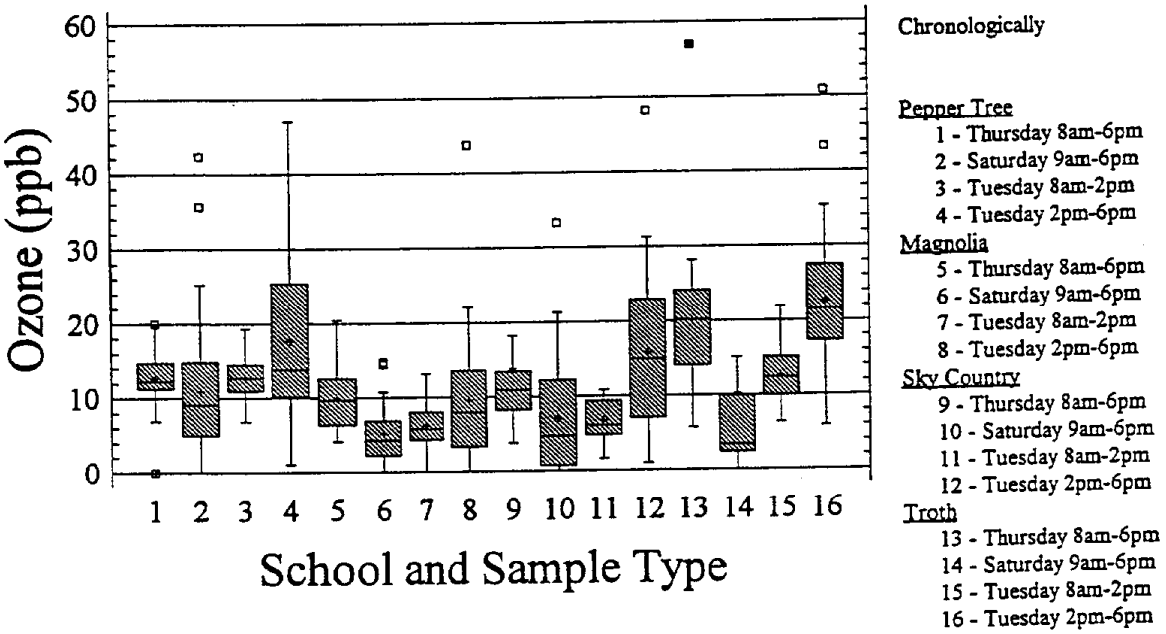


Figure 3-84. Personal ozone exposures for various schools and sample types; samples ordered chronologically.

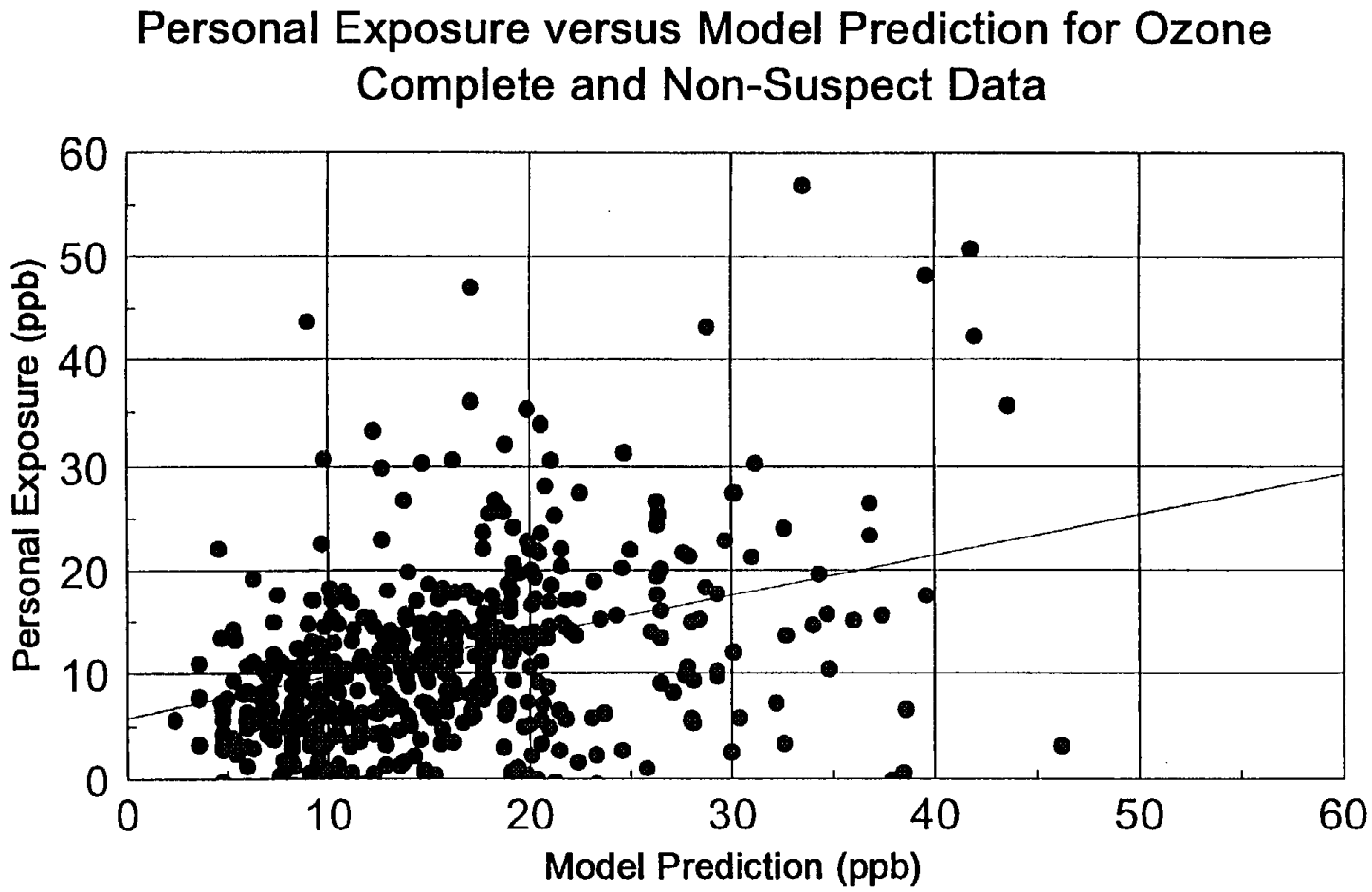


Figure 3-85. Personal ozone exposure versus model prediction for the complete and non-suspect data.

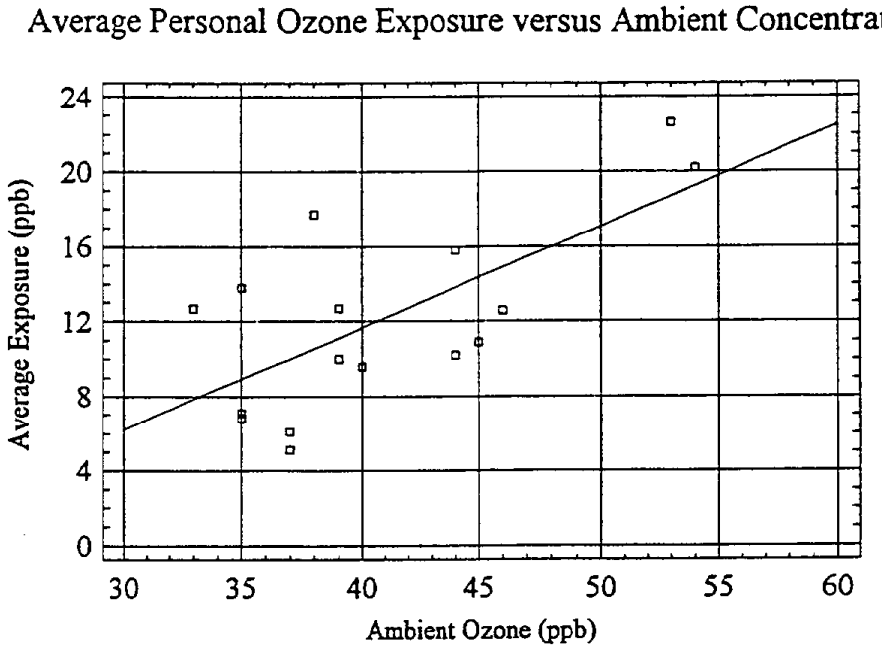


Figure 3-86. Comparison of the average personal ozone for each sample type and school with the ambient ozone concentrations.

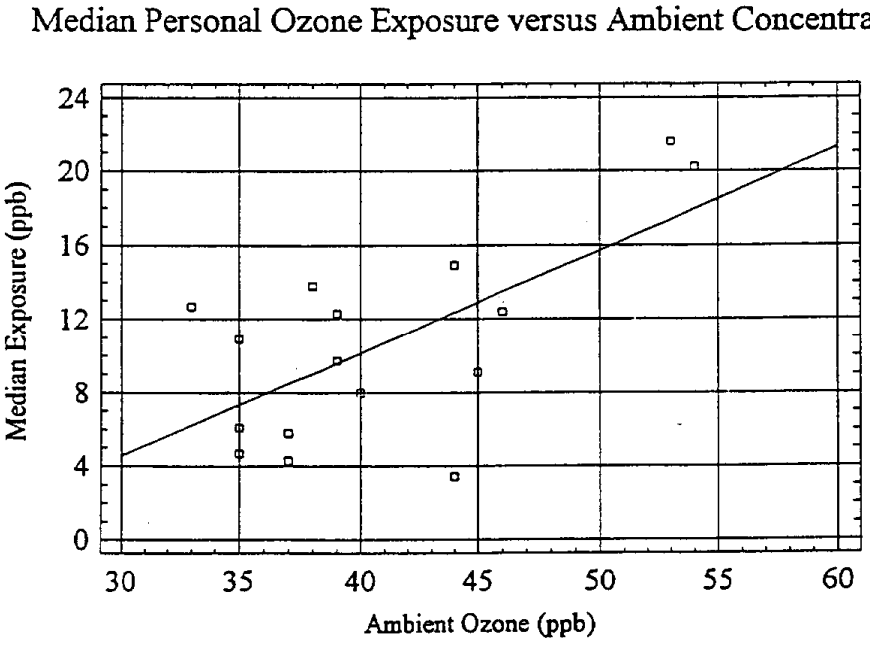


Figure 3-87. Comparison of the median personal ozone for each sample type and school with the ambient ozone concentrations.

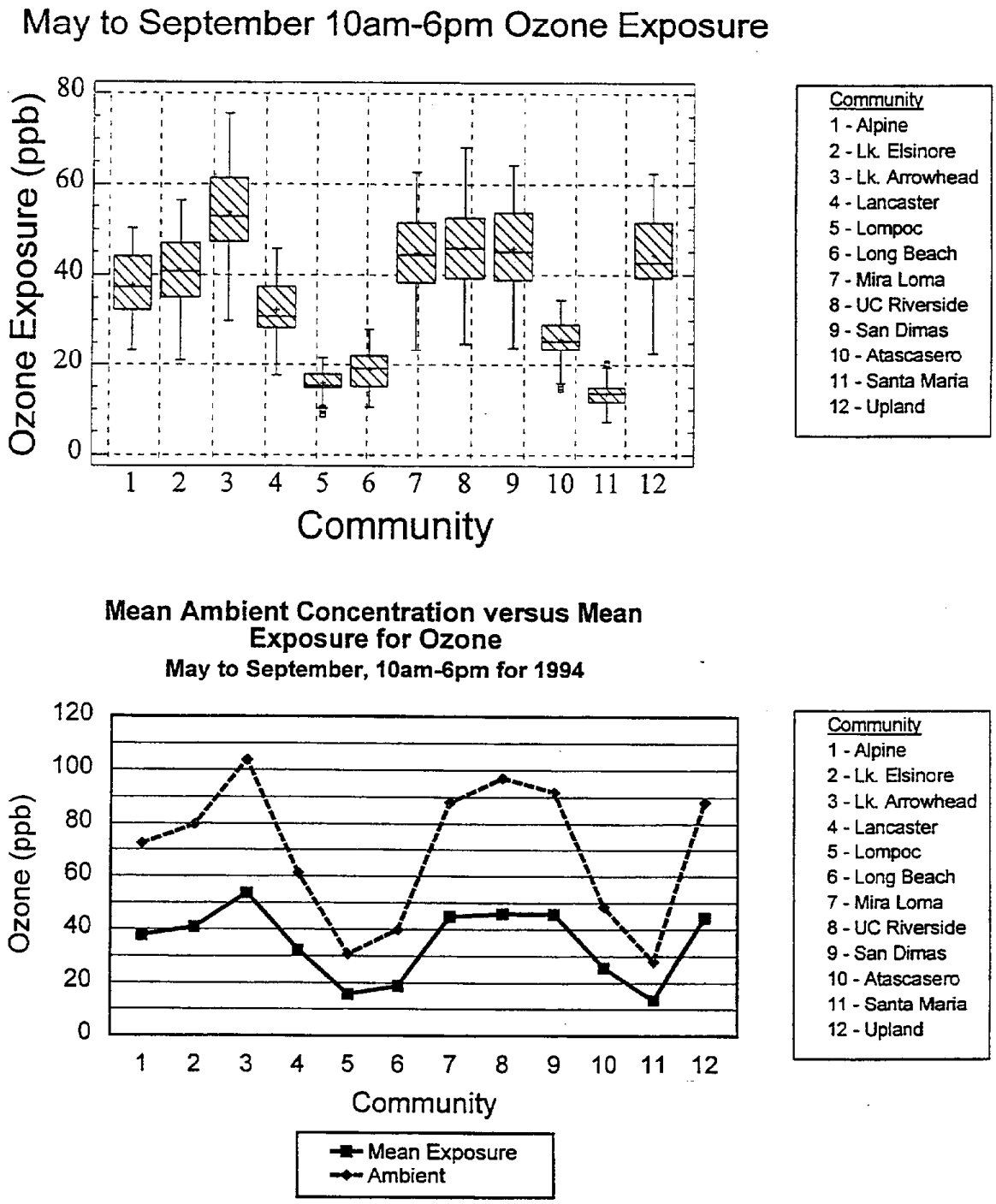


Figure 3-88. Box whisker plot of the estimated May-September 1994 10:00 a.m. to 6:00 p.m. average ozone exposure for children in the 12 communities (top); comparison of mean ambient ozone to the mean estimated exposure for May-September 1994 10:00 a.m. to 6:00 p.m. (bottom).

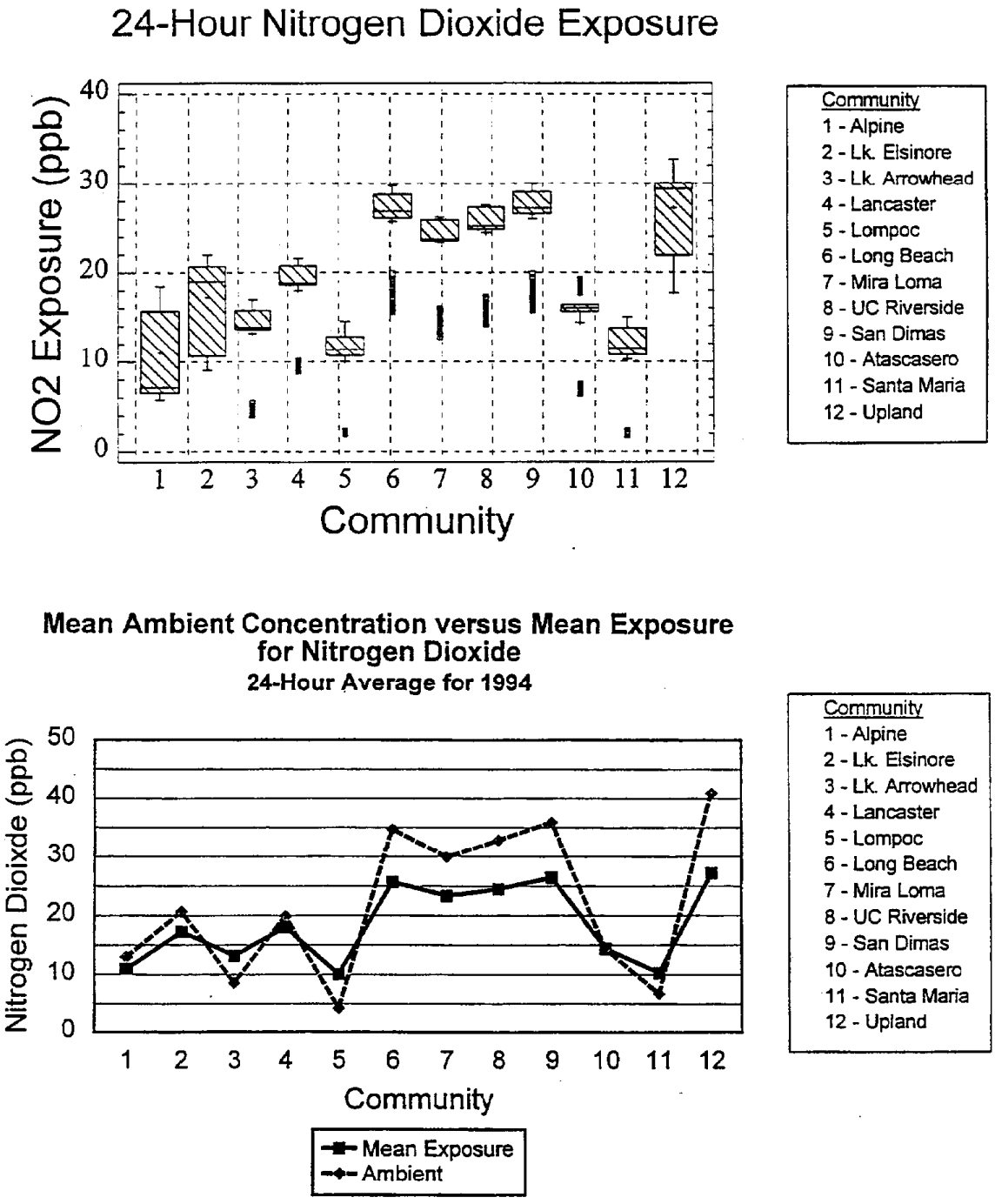


Figure 3-89. Box whisker plot of the estimated 24-hour average nitrogen dioxide exposure for children in the 12 communities for 1994 (top); comparison of the mean ambient NO_2 to the mean estimated NO_2 exposure for 1994 (bottom).